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IMPLEMENTATION OF THE MARJORIZATION PROGRAM FOR COMPUTING OPTIMUM COMBINED KINEMATIC VARIABLES ON THE HP9000/835

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Software Documentation

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IMPLEMENTATION OF THE MARJORIZATION PROGRAM FOR COMPUTING OPTIMUM COMBINED KINEMATIC VARIABLES ON THE HP9000/835

Introduction

The purpose of this report is to document the implementation of an improved and expanded version of the "Marjorization" computer program on the HP9000/835, and to present detailed instructions on the execution of this program.

An underlying assumption of the Marjorization process is that photo-derived displacements output by the Naval Biodynamics Laboratory's data analysis program, EZFLOW, are the best source for displacement variables, and EZFLOW sensor-derived accelerations are the best source for acceleration variables. Another assumption is that small corrections to various accelerometer constants can be determined, which produce very little change in the kinematic variables at the acceleration level, but which can produce significant changes in the computed displacements and can bring the corrected sensor-derived displacements into agreement with the photo-derived displacements. Marjorized variables are defined as the corrected accelerometer-derived kinematic variables obtained by applying the computed corrections to the appropriate parameters in the EZFLOW sensor program. These variables represent the optimum combination of the EZFLOW photo- and sensor-derived variables, and they provide a consistent set of kinematic variables (from the acceleration level to the displacement level) suitable for mathematical modeling.

As discussed in detail in previous publications,[1,2] the purpose of the Marjorization program is to determine the most probable corrections to accelerometer direction cosines and sensitivities and to initial Euler angles, which would bring the accelerometer-derived linear displacements and angular orientations into agreement with the corresponding photo-derived variables. The Marjorization algorithm constrains the solution for the corrections in order to deter error-component solutions that excessively exceed the *a priori* values for these components, since large corrections could significantly change the computed acceleration components. Appendix A includes a summary of the Marjorization process.

Description of the Marjorization Program

The new Marjorization program consists of three primary modules that may be executed using a single UNIX shell script *xqtmarj* (Appendix B1). A flowchart of the program, using the input and output data files required for sled run LX3959, is provided in Figure C-1. The data files for the same run are summarized in Table D-1, which also cites the tables that contain descriptions of the required data for the various modules and the figures that contain sample data files. Appendix B2 presents sample UNIX shell scripts that may be used to execute the individual Marjorization modules and the auxiliary modules.

The first module computes perturbed displacement variables using perturbation values read from a data file. The second module uses these perturbed variables to compute partial derivatives for each of the sensor parameters and computes a constrained least-squares solution for the corrections to the sensor parameters that minimize the differences between the photo-derived and sensor-derived displacements

within the context of the previously indicated constraints. The third module reads these corrections, applies them to the sensor parameters, and computes corrected kinematic variables, which are defined as Marjorized variables. There is also an auxiliary module, which rewrites the reduced EZFLOW photo-derived variables in the format required by the second Marjorization module, and a plotting module, which employs the standard routines used at the Naval Biodynamics Laboratory to generate EZFLOW plots.

The primary modules incorporate several significant improvements over the previous version of the Marjorization program, which was implemented on the UNIVAC in the 1980s. Most of the important changes are summarized in Table 1.

Table 1. Major Changes in Marjorization Program.

	Language	Max # Accel	EZFLOW Version	Iterative Solutions	Max # of Data Pts Used in Sol'n	Automated Solution
Old	Fortran IV	6	Pre-1986	No	60	No
New	Fortran 77	9	Current	Yes	150	Yes

The code is now written in FORTRAN 77 and includes all of the changes and improvements that have been implemented in EZFLOW up to the present time. In addition, the Marjorization program now computes corrections to all available accelerometers; that is, corrections are computed for all nine head accelerometers, while in the past calculations were limited to six accelerometers, since the original Marjorization code was developed when only six were used on the head. In addition, iterative solutions may now be obtained, with the iteration implemented automatically in a shell script (Appendix B1) for a predetermined number of iterations. The corrections computed for each iteration are used to update the reference values used for the next iteration, and each successive solution is linearized around the solution from the previous iteration.

The capability of inputting factors to be applied to the *a priori* variances for the individual photo-derived linear and angular displacement variables has also been implemented in the new Marjorization program. The manipulation of these factors was found to be the most effective way of improving the agreement between the Marjorized displacement variables and the photo-derived displacements, when the Marjorized variables obtained using the baseline values for these factors produced less than the desired degree of agreement. To facilitate the use of the Marjorization program with Optotrak™ solutions, the maximum number of data points to be used in the solution has also been increased from 60 to 150.

Results and Validation

The new Marjorization program was tested on thirteen sled runs (Table D-2). Sample plots comparing the Marjorized variables for sled run LX3959 with the photo-derived and accelerometer-derived variables, which will be analyzed later in this paper, are included in Figure C-2 through Figure C-13. The new program was exercised extensively on some of the runs, and based on these results, some refinements were made to the previously established nominal values for the variable input data values. The weighting

scheme for selecting data points to be included in the solution was modified to take advantage of the new capability of using up to 150 data points in the solution. Taking advantage of the new capability to apply factors to the variances for the linear and angular displacement variables, baseline factors for the head and T–1 were determined. In conjunction with this, refinements were also made to the factors previously applied to the *a priori* variances for the accelerometer direction cosines and sensitivities, as well as to the initial Euler angles.

The matrix-inversion technique used to obtain the least squares solution for the error components was also verified by implementing a method for obtaining solutions to machine accuracy obtained from the *NSWC Library of Mathematics Subroutines*,[3] labeled "Solution of Equations with Iterative Improvement." A comparison of the solutions based on the two methods revealed negligible differences.

Results obtained from iterative solutions were analyzed and the following observations were made. As previously reported,[1] it was found that a single iteration generally produced satisfactory agreement between the Marjorized variables and the photo-derived displacements without excessively large corrections to the accelerometer parameters. However, although most runs were handled well with a single iteration, in some cases enough nonlinearity exists to warrant iterative solutions.[1]

Although the bulk of the possible corrections to the sensor-derived linear and angular displacements are obtained by applying first-iteration corrections to the sensor parameters, it was found that the corrections computed for two iterations generally produced even better overall agreement between the photo-derived and accelerometer-derived displacements, without resulting in excessively large corrections to the accelerometer parameters. It was, however, generally found that very little improvement can be obtained with more than two iterations, and this usually comes at the expense of larger cumulative computed corrections, which can become unacceptably large compared to the *a priori* values for the errors in the accelerometer parameters. In addition, further iterations generally improve the off-axis displacement components, in some cases at the expense of small degradation in the midsagittal-plane displacement components, particularly the Z displacement.

Recommended Baseline Data Values. Based on an analysis of the results of a large number of computer runs for the thirteen sled acceleration tests used in this study, the following is recommended. Production solutions should be obtained using two iterations and applying the factor sets shown in Table 2 to the denominators of the photo-derived linear displacements and Euler angles. In addition, a factor of 1.0 should be applied to the *a priori* variances for the accelerometer direction cosines and sensitivities, as well as to the initial Euler angles, as compared to a factor of 3.0 that was previously used. These values, together with the revised weighting scheme for the selection of data points to be used in the solution, are included in the sample data files in Appendix B3.

Table 2. Factor Sets to be Applied to the Denominators of the Photo-Derived Linear Displacements and Euler Angles to Obtain Production Solutions.

	Linear	Angular
Head	1	10
T1	3	3

These recommendations, together with the previously established nominal values for Marjorization

input data,[4] should be used for production Marjorization runs. Nominal values for all user-required input data to the Marjorization modules are shown in sample data files provided in Appendices B3 through B8; Tables D–3 through D–8 contain descriptions of this data. Table D–9 defines the variables included in plot specification module *pltmarj*. Tables D–10 and D–11 contain descriptions of program-generated data that is input to follow-on Marjorization modules. Sample output from the Photo-Reformatting Module is show in Appendix B9. In addition, Appendix B1 provides a sample shell script which automatically cycles through the desired number of iterations (in this case, two), deleting data files as necessary in accordance with program requirements. All of the execution scripts and data files are stored on the HP9000 in the directory /7933/users/margie/MARJORIZATION, with the exception of the plot-generation scripts, which are contained in the directory /7933/users/margie/MARJORIZATION/PLOTS.

Additional iterations and/or modification of the nominal input data values could be appropriate if agreement between the Marjorized displacement variables and the photo-derived variables is less than desired, or if the computed corrections are larger than desired for a particular sled run. However, past experience has shown that less than satisfactory results from the Marjorization process often is an indication of some problem with the run data, which should be investigated and corrected if possible. In the event that it is necessary to improve the Marjorization results, manipulation of factors applied to the denominators of the *a priori* variances for photo-derived displacements was found to be effective. These factors are entered in the input file *filein* (Appendices B3 and B6).

Most of the sled runs included in this study appear to have a noticeable timing discrepancy between the photo-derived and sensor-derived X displacements for both the head and neck. Since this timing discrepancy is not generally seen in the other displacement variables, this problem appears to be the result of a discrepancy between the computed times for the sled variables and those for the head and neck variables, since sled displacement is subtracted from the head and neck X displacements in the laboratory coordinate system to obtain the X displacement in the sled coordinate system, which is the plotted variable.

For example, in Figure C-14 and Figure C-15, in which the top plot displays the head X displacement and the bottom plot the T1 X displacement, it may be seen that there is a significant discrepancy in the timing of the sensor-derived and photo-derived X displacements for both the head and neck for runs LX3965 and LX3904 respectively. In these plots the last character of the Marjorized variable name is *C*, the last character of the photo-derived variable name is *P*, and the last character of the sensor-derived variable name is *S*. Since timing discrepancies of this type cannot be corrected to any significant degree with normal Marjorization techniques, the Marjorization program was modified to permit shifting the sled acceleration trace in an effort to correct this discrepancy. A shift of only 1 msec was found to significantly improve the agreement between the X Marjorized and photo-derived displacement variables, as can be seen in Figure C-16 through Figure C-19, in which the top plot reflects the unshifted sled acceleration trace and the bottom one a 1-msec shift. Note that although there is still a significant discrepancy in the timing of the curves, this small timing shift resulted in significantly improved agreement between the Marjorized and the photo-derived X displacements for both the head and neck.

Criteria for Evaluating the Marjorization Results. Objective criteria were established for evaluating the Marjorization results on the basis of analysis of a large number of runs. These criteria are displayed at the bottom of Tables D–2, D–12, and D–13. A Marjorized linear displacement variable was judged as excellent if there was less than a 1.25-cm difference between the photo-derived and Marjorized variable in the time window of interest (between the variable peak and 250 msec). An angular displacement variable was judged as excellent if there was less than a three-degree difference between the photo-derived and Marjorized variable in the time window of interest. Because acceptable Marjorization results also

require that the corrections to the accelerometer parameters not be excessively large for runs without known problems, evaluation criteria were also established for the corrections to the accelerometer orientations and sensitivities, as well as corrections to the initial Euler angles.

An Analysis of Results for Run LX3959

Plotted results for run LX3959 comparing accelerometer-derived displacement variables (last character of the variable name *S*), photo-derived variables (last character *P*), and Marjorized variables (last character *C*) are presented in Figure C-2 through Figure C-13. Although these plots were generated before the program modification that increased the number of data points used in the solution from 60 to 150, these results do not differ significantly from those obtained with the new baseline input data values. The following analysis is based on the data in Appendix B6. However, a similar analysis would apply using the modified input data in Appendix B3. Computed corrections that were applied to the sensor parameters to generate the Marjorized variables are shown in Table D–14.

It may be seen from Figure C-2 through Figure C-7, for which the plotted variables are defined in Table D–9, that while the Marjorized curves for the head displacement variables closely approximate the photo-derived curves, the sensor-derived displacement variables drift significantly from the photo solution, with the exception of the second Euler angle in Figure C-6, in which the sensor-derived curve reasonably approximates the photo-derived curve. In addition, although the Marjorized neck displacement variables shown in Figure C-7 through Figure C-13 do not agree as well with the photo-derived variable as do the head variables, the magnitude of the differences in the time window of interest are quite small, while the sensor-derived neck displacement variables all drift away from the photo solution. Furthermore, as may be observed in Figure C-8, there is an obvious timing discrepancy between the photo-derived and sensor-derived X displacement variables, and a small shift in the time of the sled acceleration would be expected to improve the neck X results, as previously discussed.

We will now apply a more objective analysis to Figure C-2 through Figure C-13 using the evaluation criteria shown at the bottom of Table D–2. As may be observed from the plots, with the exception of the neck X-displacement, all head and neck Marjorized variables differed from the photo-derived variables by less than 1.25 cm during the time window of interest (between the curve peaks and 250 msec) and would therefore be categorized as excellent. The neck X displacement exceeds 1.25 cm by only a small amount, and therefore is classified as G+, i.e., good plus. In addition, all of the Marjorized head and neck Euler angles differed from the corresponding photo-derived Euler angles by less than 3° and were therefore classified as E (excellent). The magnitudes of all of the computed corrections to the head sensor parameters (Table D–14) were classified as excellent, although the correction to the sensitivity for accelerometer 5 was −3.5%, which is the lower limit for the excellent category. Hence the overall rating for the "Magnitude of Corrections" is E−. Because the computed correction to the orientation of neck accelerometer 2 was 4.75 degrees, which is classified as good according to the evaluation criteria, the overall "Magnitude of Corrections" rating for the neck is G. Although the neck X displacement was classified as G+, a small shift in the sled accelerometer trace would be expected to bring the Marjorized X displacement into better agreement with the photo-derived variable and this variable could then presumably be categorized as excellent.

Hence it may be seen that the small corrections to the accelerometer parameters and initial Euler angles shown in Table D–14 resulted in significant changes in the corrected accelerometer-derived displacement variables, that is, the Marjorized variables. Although no effort was made to further improve the agreement between the Marjorized and photo-derived neck X displacement by manipulating input data

values, it is believed that any substantial improvement in this variable would require shifting the sled acceleration trace.

An Analysis of the Marjorized Results for Other Sled Runs

Table D-2 presents an evaluation of the Marjorized displacement variables based on new baseline input data values for all thirteen sled acceleration tests included in this study. Both the head and the neck displacement variables were categorized according to the criteria displayed at the bottom of the table. It may be seen that for 9 of the 13 runs, all head Marjorized displacement variables were judged to be excellent, and with the exception of runs LX3959 and LX3970, the magnitude of the corrections to the head accelerometers for each of these runs was also classified as excellent. For the neck, no linear or angular displacement variable was categorized as poor. However, for the 11 runs for which data for the neck were available, only two of the 11 X displacement variables were rated as excellent, with the others rated as good. In addition, with the exception of run LX3852, the magnitude of the corrections to the T1 accelerometers were all classified as excellent.

It may be noted from Table D-2 that a less than excellent rating for the Marjorized linear and angular displacement components was for the most part observed only in the X displacement components for both the head and neck, particularly for the neck. The tendency of the X components for the head and the neck to be rated as less than excellent is almost certainly the result of the previously noted timing discrepancy, and it was previously shown that improved results can be obtained by applying a small timing shift to the sled variables (Figure C-16 through Figure C-19).

Whenever a Marjorized variable is judged to be poor, an effort should be made to improve the results. The possibility of bad data should be considered first, since this could be the source of the unsatisfactory results. In addition, some of the input data values may be manipulated to improve the agreement between the Marjorized and the photo-derived variables.

An effort was made to improve the agreement between the head Marjorized and photo-derived displacement variables for run LX3970, since the head Z-displacement component was rated as poor. In addition, although LX3904 did not have any components rated as poor, it had two head components which were less than excellent, and work on LX3904 was therefore warranted. An effort was also made to improve the Marjorized neck results for LX3959, since two of the displacement components were classified as good. For these runs the factors which were applied to the *a priori* variances for the photo-derived variables were manipulated (Table D-12). The poor result was upgraded to excellent, and three of the five variables originally categorized as good were upgraded to excellent. Note, however, that the magnitude of the corrections generally increased, although not to an unacceptable level for the factors used.

As previously discussed, a timing shift was applied to the sled acceleration for LX3904 and LX3965 in an effort to improve the X displacement components for the head and neck. It may be seen in the bottom plots in Figure C-16 through Figure C-19, which reflect this timing change, that a 1-msec timing shift resulted in much improved Marjorized X displacement components. Table D-13 presents an evaluation of the results for these timing-shift runs. It may be seen that all of the X displacement components were upgraded to excellent.

Detailed Instructions for Generating Marjorized Variables

Detailed instructions for executing the Marjorization program on the HP9000 are provided below. Also provided are instructions for gathering the required data, preparing it for the Marjorization program, and creating the required data files. Directions for generating plots comparing Marjorized, photo-derived, and sensor-derived displacement variables are included. These variables are defined in Table D–9.

The flowchart presented in Figure C-1 shows the input data required by each of the Marjorization modules and by the auxiliary modules for run LX3959. It also indicates the output from each module which is used by follow-on modules. Table D-1 summarizes the input and output data for the various Marjorization modules and lists the tables that contain descriptions of the variables and the figures that contain sample data files for the various modules.

Collect Run Data. The first step in generating Marjorized variables is to collect the data for the desired run. If reduced EZFLOW photo variables for the run are available, it is necessary to identify the directory in which they are located. This directory should be defined as unit 7; i.e., file 7, located in the directory on the HP from which the Marjorization run is to be started. File 7 should consist of a single entry, the name of the directory where the reduced EZFLOW variables are located. If the reduced EZFLOW variables are not available, it is necessary to run EZFLOW to compute them. Sensor accelerometer data should be available on unit 8; i.e., file 8 should contain only the name of the directory where the accelerometer data is located.

For example, the Marjorization program was executed for run LX3959 from the /7933/users/margie/MARJORIZATION directory with input data shown in Appendix B3 through B7 and Appendix 11. File 7 in the directory /7933/users/margie/MARJORIZATION contained the entry (without quotes) "/7963B/prod/data/esvpaper" — the directory in which the reduced EZFLOW variables (photo and sensor) for LX3959 were stored. Unit 8 contained the entry "/7963B/prod/data/sensor" — the directory in which the accelerometer data for LX3959 were stored.

Reformat Reduced Photo Variables. It is necessary to reformat the reduced photo variables to an ASCII file to be read into the second Marjorization module. Ronnie Wilson wrote the subroutine *getphodat.f* for this purpose. The driver program *marjphopgm.f* reads a data file, such as *marjphodat* (Appendix B8) from standard input. This data file consists of only two entries: the unit that contains the name of the directory in which the reduced photo variables are stored and the run number. For example, for LX3959 *marjphodat* contains the entry "7" and the run "LX3959," since file 7 contains the directory in which the reduced photo variables are stored, i.e., /7963B/prod/data/esvpaper. A description of the variables in this input file is provided in Table D–8.

The reformatted photo variables are output to files with names constructed with eight characters, the first four of which are either "head" or "neck," and the last four characters consist of the four-digit run number. For example, for run LX3959 the reformatted data files are *head3959* (Appendix B9) and *neck3959.*

The executable file, *xqtmarjpho*, which reformats the photo variables, is located in the /7933/users/ronnie/MARJORIZATION directory. The program can be executed with the *xqtpho* script shown in Appendix B2, or by entering the following command, assuming that the data file *marjphodat* contains the appropriate input data:

```
/7933/users/ronnie/MARJORIZATION/xqtmarjpho<marjphodat
```

Execution of the Marjorization Program. The Marjorization program can be executed for any sled run using a customized version of the shell script *xqtmarj* (Appendix B1). Before *xqtmarj* is executed, however, it is necessary to prepare the individual scripts and data files summarized in Table D-1 and shown in Appendices B2 through B7 and Appendix B11. Descriptions of the input data files are included in Tables D-3 through D-7 and D-11.

Sample scripts and user-defined input data files used to execute the Marjorization program for LX3959 are shown in Appendices B1 through B7 and Appendix B11. These files are currently stored on the HP9000 in the directory /7933/users/margie/MARJORIZATION. If the data specified above are available and if only baseline input data are to be used for the run, then the only changes required to the scripts and data files are to change each "3959" in the data file to the appropriate four-digit sled run number in files *xqtmarj*, *data1*, *data2*, *data3*, and *corrzero*. If the anatomical mounts for the head and T1 are other than 1101 and 2201, it is also necessary to provide perturbation files for the anatomical mounts used, similar to the files shown in Appendix B4. (See Table D-3 for a definition of the data variables). The naming convention for these files is "d" concatenated with the four-digit anatomical mount number.

Once the scripts and data files have been prepared, the Marjorization program may be executed by entering the following at the "$" prompt on the HP9000:

```
xqtmarj
```

The script *xqtmarj* provides for the execution of all three primary Marjorization modules. Iterative solutions are generated by the "for" loop in this file. Two iterations are obtained with the command on line 3 of *xqtmarj*:

```
for i in corr1 corr2
```

If three iterations are desired, then the user should append a space and "corr3" to the above line. Any desired number of iterations can be obtained similarly.

The sequence of operations specified in the script *xqtmarj* is as follows:

1. Prior to the start of the iteration loop, the script copies the file *corrzero* (containing all zero corrections) to the file *corr3959* to initialize the correction file for the first iteration.
2. The script then initiates a loop in which script *run1* (Appendix B2) executes Marjorization Module 1 using the corrections to the sensor parameters found in file *corr3959* to compute reference values for the sensor parameters to which perturbations are applied. The output from Marjorization Module 1 is the file *out3959*, which contains perturbed and unperturbed sensor parameter values. The master script *xqtmarj* (Appendix B1) then copies the correction file *corr3959* to the old correction file *oldc3959*, deletes *corr3959*, and runs script *run2* (Appendix B2), which executes Marjorization Module 2. Corrections from *oldc3959* are applied to the sensor parameters, which become the reference values about which the constrained least-squares solution is linearized to compute corrections to the sensor parameters for that iteration. Cumulative corrections are written to the file *corr3959*, which is read by Marjorization Module 1 for the next iteration.
3. After the execution of script *run2* for the final iteration, the master script *xqtmarj* runs script *run3* (Appendix B2), which executes Marjorization Module 3. Module 3 reads the corrections contained in *corr3959*, applies them to the sensor parameters, and generates corrected sensor

variables, which are defined as Marjorized variables.

Detailed information on the execution of the individual Marjorization modules is presented below.

Execution of Marjorization Module 1. Execution of Marjorization Module I may be accomplished by executing the script *run1* shown in Appendix B2. This runs the executable program *xqtmarjpt1i* located in the directory /7933/users/ronnie/MARJORIZATION. This program requires File 7 to contain the name of the directory in which the EZFLOW reduced photo variables (and sensor variables) for the given run are stored, e.g., /7963B/prod/data/esvpaper for LX3959 data. File 8 must contain the name of the directory in which the accelerometer data are stored, e.g., /7963B/prod/data/sensor for LX3959 sensor data.

Files containing deltas to be applied to the head and neck mount accelerometer direction cosines, sensitivities, and initial Euler angles to generate perturbed values must be available in the current directory. A file must be provided for each mount, and the file name must be constructed as "d" concatenated with the four-digit anatomical mount number. For example, if the head and neck anatomical mounts are 1101 and 2201 respectively, then the deltas must be stored in files named *d1101* and *d2201* (Appendix B4). Data required from standard input are described in Table D–4, and sample data are shown in data file *data1* in Appendix B5.

In order to permit iterative solutions with linearization around the solution from the previous iteration, the program reads in corrections to be applied to the accelerometer parameters for each iteration. On the first iteration, the program must read all zero corrections. Hence, a data file in which all corrections are set to 0 must be provided, e.g., *corrzero* (Appendix B11). On line 2 of *xqtmarj*, this data file with zero corrections is copied to the correction file to be used for that iteration, e.g., *corr3959*. The name of this correction file is the concatenation of "corr" and the four-digit run number, e.g., *corr3959* for run LX3959. On successive iterations the correction file contains computed corrections output by Marjorization Module 2 on the previous iteration.

Output from Marjorization module 1 is a file containing the perturbed and unperturbed values for the sensor-derived linear displacements and quaternions. This data file contains unperturbed and perturbed sensor-derived variables obtained by applying the perturbation values shown in Appendix B4 and described in Table D–3. This file contains identifying information such as run number, data type (head or neck), number of data points, time increment, and the magnitude of the perturbation applied. For each displacement variable it contains both the unperturbed value, and the perturbed value for each perturbation applied to a sensor parameter. The file name is the concatenation of "out" and the four-digit run number, e.g., *out3959*. The program assumes that this file does not exist. If it does, it is necessary to delete it.

Sample script *run1* in Appendix B2 may be used to execute this module for LX3959. Note that the master script *xqtmarj* (Appendix B1) contains a command to delete the file *out3959* if it exists. Script *run1* contains the command to execute Marjorization module 1 with data for LX3959:

```
/7933/users/ronnie/MARJORIZATION/xqtmarjpt1<data1
```

In addition to the writing data to *out3959*, reduced EZFLOW unperturbed sensor variables named with lower-case letters are written to unit 7 by this module.

Execution of Marjorization Module 2. Execution of Marjorization Module 2 may be accomplished by executing the script *run2* (Appendix B2). Marjorization Module 2 requires an input file whose name is the concatenation of "oldc" and the four-digit run number, e.g., *oldc3959*, which contains corrections from the previous iteration. (For the first iteration, of course, the corrections would be all zeroes). The

format for this file is shown in Appendix B10. Module 2 also requires the Module 1 output file "out" plus the four-digit run identification number ("runid"), as well as reduced head and neck photo variables, which must be stored in files named "head" plus the four-digit runid and "neck" plus the four-digit runid. For run LX3959 these files are *out3959*, *head3959*, and *neck3959*. The program also requires that there not be an existing correction file, such as *corr3959*, since this file is produced by the program.

Master script *xqtmarj* (Appendix B1) contains commands to copy the existing correction file from the previous iteration, *corr3959*, to the input file *oldc3959*, and to delete the file *corr3959* as required by the program. Script *run2* contains the command to run the executable program *xqtmarjpt2i*, which is located in the /7933/users/ronnie/MARJORIZATION directory. Correction values read from *oldc3959* are applied to the sensor parameters, which become the reference values about which the constrained least-squares solution is linearized to compute corrections to the sensor parameters for that iteration. The program reads the file *filein* (Appendix B6) from standard input. A description of the input variables in *filein* is provided in Table D-5. *Filein* contains the name of the data file that contains additional run data, such as *data2* (Appendix B6), as well as factors to be applied to the denominators of the variances for the *a priori* photo-derived displacement variables. A description of the input data variables in *data2* is provided in Table D-6. Note that this method of entering the data was used to facilitate use of the debugger without having to enter the Marjorization data from the keyboard.

Output from Marjorization Module 2 is a file named "corr" plus the four-digit runid, e.g., *corr3959*, which contains the cumulative corrections to the direction cosines, sensitivities, and initial Euler angles for both the head and neck, which are computed by Marjorization Module 2. These corrections are required by Marjorization Module 3 and are also read by Marjorization Module 1 when iterative solutions are obtained.

Marjorization Module 2 may be executed without using script *run2* by entering the following command after the appropriate data files have been provided as described above:

```
/7933/users/ronnie/MARJORIZATION/xqtmarjpt2i<filein
```

Execution of Marjorization Module 3. Execution of Marjorization Module 3 may be accomplished by executing the script *run3* (Appendix B2). This script runs the executable program *xqtmarjpt3*, which is located in directory /7933/users/ronnie/MARJORIZATION. This program requires three lines of input from the standard input device, as shown in file *data3* in Appendix B7. A description of data variables is provided in Table D-7. The program also requires a file with corrections, such as *corr3959* (Appendix B10), which is output by Marjorization Module 2, to be applied to the accelerometer parameters. It also requires access to reduced photo variables on unit 7 and accelerometer data on unit 8, as discussed for Marjorization Module 1.

Output from this module consists of Marjorized variables, which are corrected sensor-derived variables named with upper-case letters, and with a final letter "C." The Marjorized variables are stored in the directory specified in file 7.

The following command may be used to execute this module, if script *run3* is not used, once the required data files have been provided:

```
/7933/users/ronnie/MARJORIZATION/xqtmarjpt3<data3
```

Plotted Output. Plots of Marjorized variables may be obtained using the usual Data Systems plot programs. Sample plotting elements as well as shell scripts to automatically generate plots are stored in the directory /7933/users/margie/MARJORIZATION/PLOTS.

Standard plotted output for each Marjorization run is a set of 12 plots comparing Marjorized linear and angular displacement variables (file name ending with the letter "C"), photo-derived variables (final letter "P"), and sensor-derived variables (final letter "S"). Definitions of the plotted variables are provided in Table D–9. Figure C-2 through Figure C-13 are a standard set of plots for LX3959.

These plots may be generated using a customized version of the plot specification file *pltmarj*, which is stored on the HP9000 in the directory /7933/users/margie/MARJORIZATION/PLOTS. Customization of this file consists of replacing the four-digit run number in the existing file with the desired run number and changing the title on line 39 as appropriate. In addition, the units on which the variables to plot are located must be provided on lines 9 and 10 of the file *pltmarj*. For example, for LX3959 line 9 contained the entry "1" and file 1 contained the entry "/7963B/prod/data/esvpaper," the directory in which the Marjorized, photo-derived, and sensor-derived variables were stored.

The script *autoplt* shown in Appendix B2 may be used to automatically generate these plots to the screen of an HP2627 terminal; it is set up to read the post-processor file *pop2627* in the above directory. To generate hardcopy plots, the autoplt script may be modified to read the post-processor file *pop7550*; then at the "$" prompt this command may be entered:

```
$plot7550
```

Alternately, after generating screen plots, hardcopy plots may be executed by entering

```
$xqt_pop<pop7550
```

and then entering

```
$plot7550
```

Summary and Conclusions

Marjorized variables suitable for mathematical modeling may be obtained by using the procedures described in this document. Detailed instructions for generating Marjorized variables have been provided above, and nominal values for all input data appear in the accompanying tables and appendices. The baseline data values described in this paper are appropriate for production-type runs. Marjorized results may be evaluated using the criteria specified in Table D–2. If the evaluation of Marjorized variables generated with the baseline data values results in less than the desired agreement between the photo-derived and Marjorized displacement variables, it would be appropriate to first investigate the possibility that there is a problem with the data, and then to manipulate input data as previously described to improve this agreement.

Several extensions to the Marjorization program are desirable for future implementation. The capability of computing corrections to the angular velocity sensors would be useful in Marjorizing the more recent sled runs, which employ angular velocity sensors. In addition, the capability to input variable time shifts for the sled acceleration trace should be implemented as an option.

References

1. Naval Biodynamics Laboratory, memorandum by M. R. Seemann on the implementation of an algorithm for obtaining an optimum combined solution for the linear and angular kinematic variables based on both photographic and accelerometer data, New Orleans, LA, 21 April 1981.
2. Seemann, M. R. and Lustick, L. S., “Combination of Accelerometer and Photographically Derived Kinematic Variables Defining Three-dimensional Rigid Body Motion,” *Proceedings of the Second International Symposium of Biomechanics Cinematography and High Speed Photography*, Society of Photo-Optical Instrumentation Engineers, Bellingham, WA, 1981, pp. 133–140.
3. Morris, Alfred H., Jr., *NSWC Library of Mathematics Subroutines*, Naval Surface Warfare Center, Dahlgren, VA, January 1993.
4. Naval Biodynamics Laboratory, memorandum by M. R. Seemann on how to generate Marjorized variables, New Orleans, LA, 8 March 1983.
5. Naval Biodynamics Laboratory, memorandum by L. Lustick and H. G. Williamson on errors in derived kinematic variables determined from a fixed accelerometer configuration, New Orleans, LA, 1980.

Appendix A
Summary of the Marjorization Process

Assumptions:

(1) EZFLOW photo-derived displacements are the best source of displacement variables.
(2) EZFLOW sensor-derived accelerations are the best source of acceleration variables.
(3) Small corrections to various accelerometer constants can be determined; these corrections:
   (a) Produce very little change in the acceleration variables
   (b) Can produce significant changes in the computed displacements
   (c) Bring the corrected sensor-derived displacements into agreement with the photo-derived displacements

Marjorized Variables: The corrected accelerometer-derived kinematic variables obtained by applying the computed corrections to the appropriate parameters in the EZFLOW sensor program. These provide a consistent set of kinematic variables from the acceleration to the displacement level.

Corrections: The following corrections are intended to bring the accelerometer-derived linear displacements and angular orientations into agreement with the corresponding photo-derived variables:

(1) Accelerometer direction cosines
(2) Accelerometer sensitivities
(3) Initial Euler angles

Constraints: The algorithm includes constraint terms intended to deter excessively large computed correction components.

Appendix B
Sample Scripts and Data Files

B1. Shell Script *xqtmarj* to Execute Marjorization Program for LX3959 with Two Iterations

(See Appendix B2 for the individual module scripts.)

```
#xqtmarj
cp corrzero corr3959    #initialize correction components to 0.
for i in corr1 corr2
do
echo correction no. $i
rm out3959              #delete old file - this is output by Module 1
run1>/7914/atbmodel/out1
cp corr3959 oldc3959    #copy old correction file to oldc3959
rm corr3959             #delete old file - this is output by Module 2
run2>/7914/atbmodel/out2
cp corr3959 $i          #store corrections in files corr1, etc.
done
run3>out3
#print data files and final output
lp xqtmarj run1 run2 data1 data2 filein corr1 run3 data3 corr3959 out3
```

B2. UNIX Shell Scripts to Execute Individual Marjorization Modules

script *run1* — Marjorization Module 1:

```
#execute Module 1 with data file data1
/7933/users/ronnie/MARJORIZATION/xqtmarjpt1i<data1
```

script *run2* — Marjorization Module 2:

```
#execute Module 2 with data file filein
/7933/users/ronnie/MARJORIZATION/xqtmarjpt2i<filein
```

script *run3* — Marjorization module 3:

```
#execute Module 3 with data file data3
/7933/users/ronnie/MARJORIZATION/xqtmarjpt3<data3
```

script *xqtpho* — reformat photo-derived variables required by module 2:

```
#execute photo-reformatting module with data file marjphodat
/7933/users/ronnie/MARJORIZATION/xqtmarjpho<marjphodat
```

script *autoplt* — generate comparison plots of photo-derived, accelerometer-derived, and Marjorized displacement variables:

```
$xqt_specs < pltmarj > out      #plot specs from file pltmarj
tail out
$xqt_plot
mv popfil.dat meta.dat
$xqt_pop < pop2627              #display plots on screen of HP2627A terminal
```

B3. Baseline Input Data Files for Marjorization Module 2

(See Table D-5 for definitions of data entries in *filein* and *data2*.)

Data file *filein*:

```
data2
     1.0     1.0     1.0     10.0     10.0     10.0
     3.0     3.0     3.0     3.0      3.0      3.0
```

Data file *data2*:

```
LX3959 0 1 1.0000 1.0000
 0.0700 0.1000 0.1800 0.2300 0.2500 0.2900 0.3090
 0.0700 0.1000 0.1800 0.2300 0.2500 0.2900 0.3090
  1  2  2  2  2  2  1
  1  2  2  2  2  2  1
```

B4. Sample Data Files for Input to Marjorization Module 1 — Perturbation Values for Accelerometer Parameters
(See Table D-3 for definitions of data in *d1101* and *d2201*.)

Data file *d1101*:

```
amnt 1101 DELTAS FOR MARJORIZATION
                  0.0087178
                  0.0087178
                  0.0060000
                  0.0061644
                  0.0061644
                  0.0060000
                  0.0061644
                  0.0061644
                  0.0060000
                  0.0061644
                  0.0061644
                  0.0060000
                  0.0087178
                  0.0087178
                  0.0060000
                  0.0087178
                  0.0087178
                  0.0060000
                  0.0061644
                  0.0061644
                  0.0060000
                  0.0061644
                  0.0061644
                  0.0060000
                  0.0061644
                  0.0061644
                  0.0060000
                  0.0435890
                  0.0435890
                  0.0435890
```

Data file *d2201:*

```
amnt 2201 DELTAS FOR MARJORIZATION
                  0.0087178
                  0.0087178
                  0.0060000
                  0.0061644
                  0.0061644
                  0.0060000
                  0.0061644
                  0.0061644
                  0.0060000
                  0.0061644
                  0.0061644
                  0.0060000
                  0.0087178
                  0.0087178
                  0.0060000
                  0.0087178
                  0.0087178
                  0.0060000
                  0.0061644
                  0.0061644
                  0.0060000
                  0.0061644
                  0.0061644
                  0.0060000
                  0.0061644
                  0.0061644
                  0.0060000
                  0.0435890
                  0.0435890
                  0.0435890
```

B5. Sample Input Data File for Marjorization Module 1
(See Table D-4 for definitions of the data entries.)

Data file *data1*:

```
 1 0
LX3959
EOFEOF
```

B6. Original Marjorization Module 2 Input Data Files for LX3959 — Used for Plots in Figure C-2 through Figure C-13.
(See Table D–5 for definitions of data entries in *filein* and *data2*.)

Data file *filein*:

```
data2
     1.0      1.0       1.0       10.0      10.0      10.0
     5.0      5.0       5.0       5.0       5.0       5.0
```

Data file *data2*:

```
LX3959 0 1 3.0000 3.0000
 0.1200 0.1600 0.2000 0.2600 0.2850 0.2900 0.2990
 0.1200 0.1600 0.2000 0.2600 0.2850 0.2900 0.2990
 12   3   2   1   2   2   2
 12   3   2   1   2   2   2
```

B7. Sample Input Data File for Marjorization Module 3
(See Table D–6 for definitions of data entries in *data3*.)

Data file *data3*:

```
 1 0
LX3959
EOFEOF
```

B8. Sample Input Data for Photo-Reformatting Marjorization Module
(See Table D–7 for definitions of data entries in *marjphodat*.)

Data file *marjphodat*:

```
 7 LX3959
```

B9. Sample Output from Photo-Reformatting Module

(See Table D-10 for a description of the output data variables.)

Initial records from output data file *head3956*:

time	daxsop	daysop	dazsop	4hoo1p	4hoo2p	4hoo3p	4hoo4p
.00000000E+00	-.12818400E+01	-.61871698E-02	.15472900E+01	.31407000E-02	.45032799E-01	-.60249101E-01	.99715799E+00
.20999999E-02	-.12816900E+01	-.62933699E-02	.15474700E+01	.31764901E-02	.45814399E-01	-.60080100E-01	.99713397E+00
.41999999E-02	-.12815500E+01	-.64227101E-02	.15476000E+01	.32420501E-02	.46512399E-01	-.59898999E-01	.99711400E+00
.62000002E-02	-.12814000E+01	-.65447502E-02	.15477300E+01	.33655199E-02	.47111899E-01	-.59710801E-01	.99709803E+00
.82999999E-02	-.12812300E+01	-.66269902E-02	.15478600E+01	.34829599E-02	.47610600E-01	-.59601299E-01	.99708098E+00
.10400000E-01	-.12810900E+01	-.66442299E-02	.15480100E+01	.35691799E-02	.48112199E-01	-.59654500E-01	.99705303E+00
.12500000E-01	-.12810100E+01	-.66255000E-02	.15481400E+01	.35541400E-02	.48556101E-01	-.59780400E-01	.99702400E+00
.14600000E-01	-.12809900E+01	-.65756901E-02	.15481600E+01	.33876901E-02	.48745200E-01	-.59967801E-01	.99700397E+00
.16600000E-01	-.12810000E+01	-.65045301E-02	.15481400E+01	.32117399E-02	.48854899E-01	-.60245302E-01	.99698198E+00
.18700000E-01	-.12809900E+01	-.64474801E-02	.15481600E+01	.30743701E-02	.49071699E-01	-.60545899E-01	.99695402E+00
.20800000E-01	-.12809800E+01	-.64249299E-02	.15482600E+01	.30203301E-02	.49456500E-01	-.60688499E-01	.99692601E+00
.22900000E-01	-.12809500E+01	-.64345398E-02	.15484000E+01	.30582100E-02	.49944300E-01	-.60641401E-01	.99690402E+00
.24900001E-01	-.12808900E+01	-.64749299E-02	.15485300E+01	.31604299E-02	.50376698E-01	-.60544100E-01	.99688798E+00
.27000001E-01	-.12808200E+01	-.65434598E-02	.15486400E+01	.32834101E-02	.50768901E-01	-.60396500E-01	.99687701E+00
.29100001E-01	-.12807300E+01	-.65855100E-02	.15487400E+01	.33284500E-02	.51139500E-01	-.60348399E-01	.99686098E+00
.31199999E-01	-.12806300E+01	-.65697301E-02	.15488000E+01	.33163701E-02	.51481500E-01	-.60514499E-01	.99683303E+00
.33199999E-01	-.12805400E+01	-.65265601E-02	.15488300E+01	.32704901E-02	.51751200E-01	-.60649201E-01	.99681097E+00
.35300002E-01	-.12805001E+01	-.64823702E-02	.15488300E+01	.31415599E-02	.51875200E-01	-.60647000E-01	.99680501E+00
.37400000E-01	-.12804700E+01	-.64328201E-02	.15488300E+01	.30280000E-02	.51982000E-01	-.60719401E-01	.99679601E+00
.39500002E-01	-.12803800E+01	-.63623800E-02	.15488300E+01	.29947199E-02	.52123301E-01	-.60985200E-01	.99677199E+00
.41600000E-01	-.12802401E+01	-.62804399E-02	.15488501E+01	.29461300E-02	.52233100E-01	-.61304599E-01	.99674702E+00
.43600000E-01	-.12801000E+01	-.62605599E-02	.15489200E+01	.29510399E-02	.52438200E-01	-.61341599E-01	.99673402E+00
.45699999E-01	-.12799600E+01	-.63040499E-02	.15490100E+01	.30764299E-02	.52690301E-01	-.61173800E-01	.99673003E+00
.47800001E-01	-.12797700E+01	-.64216801E-02	.15491000E+01	.33561101E-02	.52951101E-01	-.60996499E-01	.99672598E+00
.49899999E-01	-.12794501E+01	-.65201302E-02	.15491700E+01	.37171999E-02	.53195398E-01	-.61008200E-01	.99671102E+00
.51899999E-01	-.12790200E+01	-.65599699E-02	.15492100E+01	.40328498E-02	.53384699E-01	-.61159998E-01	.99668998E+00
.54000001E-01	-.12784801E+01	-.66446601E-02	.15492200E+01	.42569200E-02	.53559098E-01	-.61145000E-01	.99668097E+00
.56100000E-01	-.12778000E+01	-.67893001E-02	.15492400E+01	.44289199E-02	.53767700E-01	-.60949899E-01	.99668097E+00
.58200002E-01	-.12769099E+01	-.69540502E-02	.15493000E+01	.47370102E-02	.54104000E-01	-.60766999E-01	.99667299E+00
.60199998E-01	-.12757500E+01	-.71271299E-02	.15494000E+01	.52094599E-02	.54637499E-01	-.60704999E-01	.99664497E+00
.62300000E-01	-.12742200E+01	-.72643501E-02	.15494800E+01	.56914398E-02	.55267200E-01	-.60934100E-01	.99659300E+00
.64400002E-01	-.12722300E+01	-.72960602E-02	.15495200E+01	.60308501E-02	.55903502E-01	-.61594799E-01	.99651402E+00
.66500001E-01	-.12697600E+01	-.72173099E-02	.15494800E+01	.61889901E-02	.56409702E-01	-.62691197E-01	.99641597E+00
.68499997E-01	-.12667700E+01	-.71332902E-02	.15492899E+01	.61347801E-02	.56601800E-01	-.64038202E-01	.99631900E+00
.70600003E-01	-.12631500E+01	-.71297898E-02	.15489399E+01	.58857398E-02	.56569900E-01	-.65383904E-01	.99623501E+00
.72700001E-01	-.12589200E+01	-.73638898E-02	.15484101E+01	.55746199E-02	.56465302E-01	-.66281497E-01	.99618500E+00
.74800000E-01	-.12541800E+01	-.78679603E-02	.15476800E+01	.53333300E-02	.56341399E-01	-.66467598E-01	.99618101E+00
.76800004E-01	-.12490100E+01	-.85377796E-02	.15467300E+01	.50181202E-02	.56299899E-01	-.66011101E-01	.99621600E+00
.78900002E-01	-.12434700E+01	-.92312200E-02	.15455000E+01	.44447999E-02	.56401901E-01	-.65122098E-01	.99627000E+00

B10. Computed Corrections for LX3959, Iteration 2

Data file *corr3959* must be initialized to all zero components prior to executing Marjorization Module 1. This is accomplished by copying the file *corrzero* (Appendix B11) into the file *corr3959*. The script *xqtmarj* in Appendix B1 accomplishes this by the command on line 2 of this script. In this way Marjorization Module 1 does not apply any corrections on the first iteration. The correction file *corr3959* must be copied to the file *oldc3959* (representing corrections from the previous iteration), and *corr3959* must be deleted, since this file is output by Marjorization Module 2. This is accomplished automatically by the commands on lines 8 and 9 of script *xqtmarj* . Marjorization Module 2 then computes corrections for the current iteration which are stored in *corr3959*. This file is input to Marjorization Module 1 for successive iterations. The file *corr3959* output by Marjorization Module 2 on the final iteration is then read and applied by Marjorization Module 3. (See page 9 for definitions of the data variables.)

Data file *corr3959* (also *oldc3959* for the next iteration):

```
LX3959 head 30
.24294318E-02  -.31496771E-01  -.32798197E-01  -.13303082E-01  -.24283137E-02  .13652002E-01  .59324950E-02  .10798099E-02
.38662687E-03  -.21047810E-01  -.15495104E-01  .80997190E-02  -.11127490E-01  .57574682E-01  -.35145398E-01  -.13571342E-01
-.36559019E-01  -.32545082E-01  .54189600E-02  .55972673E-02  .53501730E-02  .70709427E-03  .13681426E-01  .40426627E-02
-.75414074E-02  -.11959825E-01  .15625632E-02  .11073915E-01  -.17082024E-01  -.84116291E-02
LX3959 neck 21
.61505148E-02  -.14609219E-01  .16736757E-01  -.31609792E-01  .26931331E-01  -.45282622E-02  -.55842516E-02  -.29034908E-02
-.24462903E-02  -.90931058E-02  -.27408332E-01  .24642549E-01  .43903468E-02  .48344713E-02  -.34537378E-02  .10331963E-01
.46454081E-02  -.62716762E-02  .11845039E-01  -.12529074E-01  -.64224275E-02
```

B11. All-Zero Corrections for LX3959 — Initial Corrections Read by Marjorization Module 1

(See page 9 for definitions of the data variables.)

Data file *corrzero*.

```
LX3959 head 30
.00000000E+00  .00000000E+00  .00000000E+00  .00000000E+00  .0000000000E+00  .0000000000E+00  .00000000E+00  .00000000E+00
.00000000E+00  .00000000E+00  .00000000E+00  .00000000E+00  .0000000000E+00  .0000000000E+00  .00000000E+00  .00000000E+00
.00000000E+00  .00000000E+00  .00000000E+00  .00000000E+00  .0000000000E+00  .0000000000E+00  .00000000E+00  .00000000E+00
.00000000E+00  .00000000E+00  .00000000E+00  .00000000E+00  .0000000000E+00  .0000000000E+00
LX3959 neck 21
.00000000E+00  .00000000E+00  .00000000E+00  .00000000E+00  .0000000000E+00  .0000000000E+00  .00000000E+00  .00000000E+00
.00000000E+00  .00000000E+00  .00000000E+00  .00000000E+00  .0000000000E+00  .0000000000E+00  .00000000E+00  .00000000E+00
.00000000E+00  .00000000E+00  .00000000E+00  .00000000E+00  .0000000000E+00
```

Appendix C
Figures

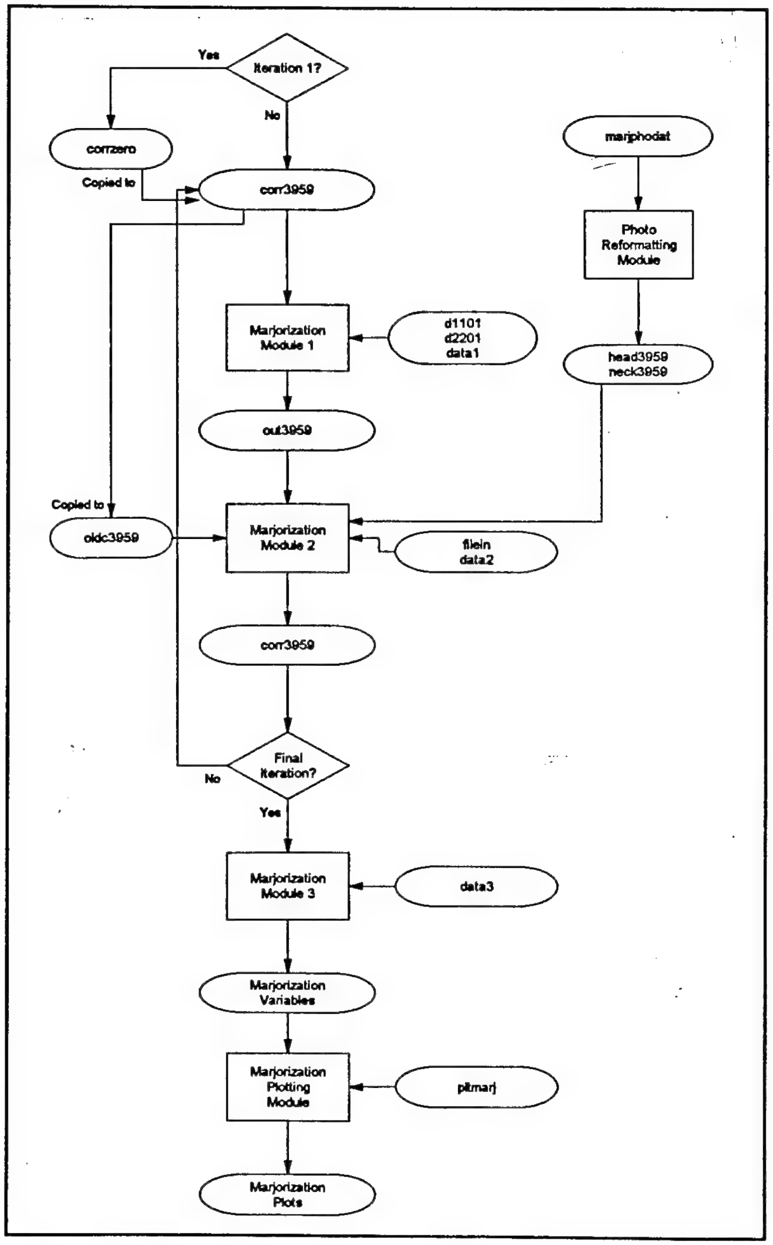


Figure C-1
Marjorization Program Flowchart for LX3959

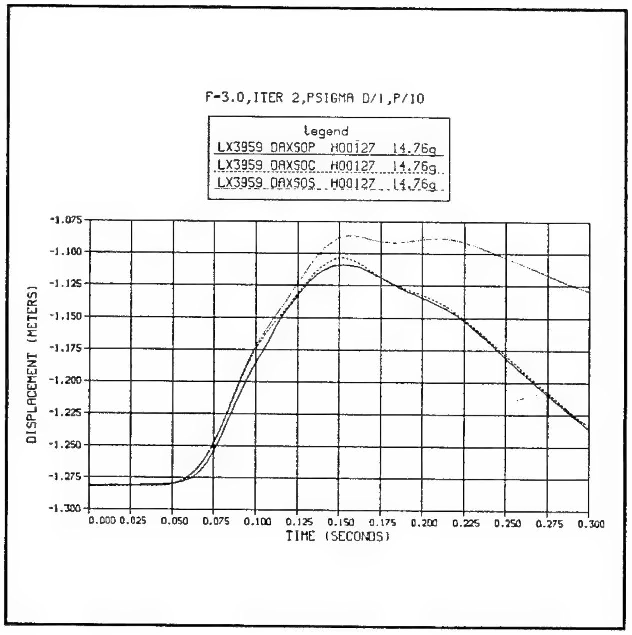


Figure C-2
Comparison of Photo-Derived (P), Marjorized (C) and
Sensor-Derived (S) Head Anatomical X Displacements

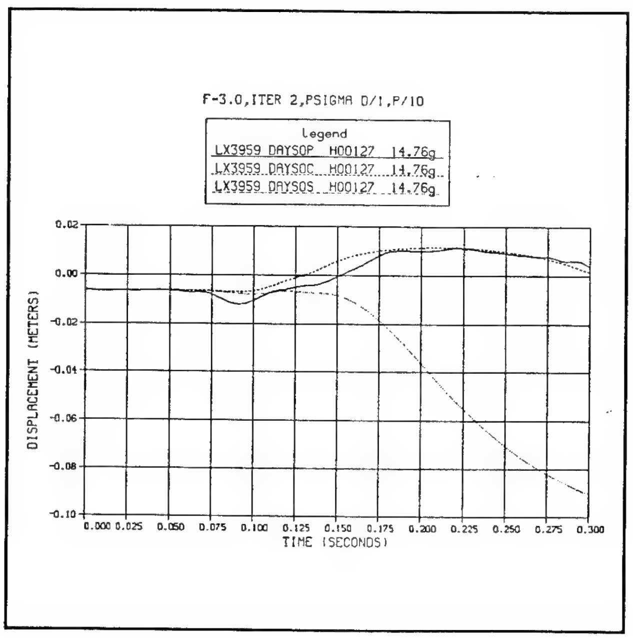


Figure C-3
Comparison of Photo-Derived (P), Marjorized (C), and
Sensor-Derived (S) Head Anatomical Y Displacements

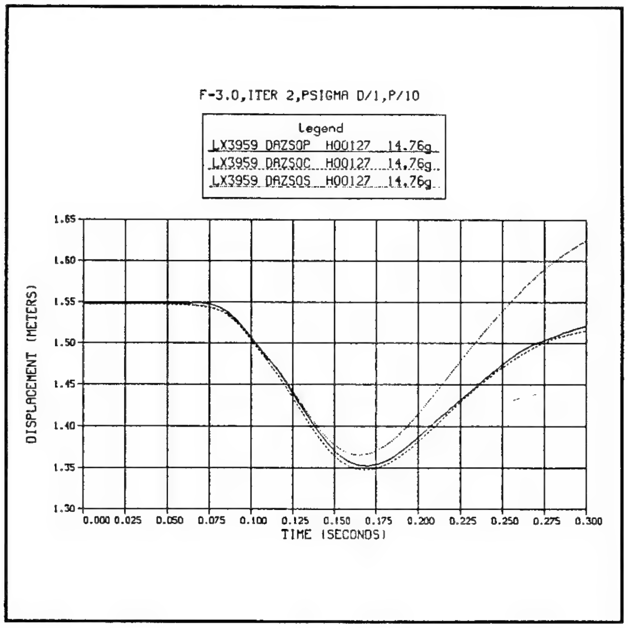


Figure C-4
Comparison of Photo-Derived (P), Marjorized (C), and Sensor-Derived (S) Head Anatomical Z Displacements

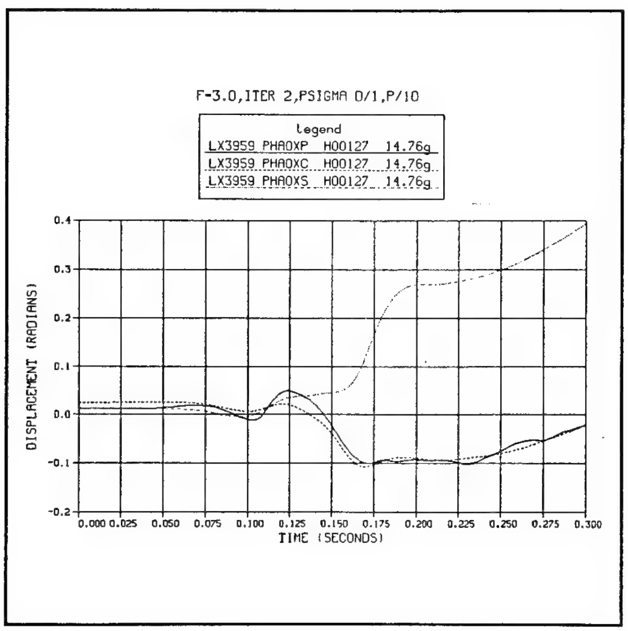


Figure C-5
Comparison of Photo-Derived (P), Marjorized (C), and Sensor-Derived (S) Rotations About Head Anatomical X Axis

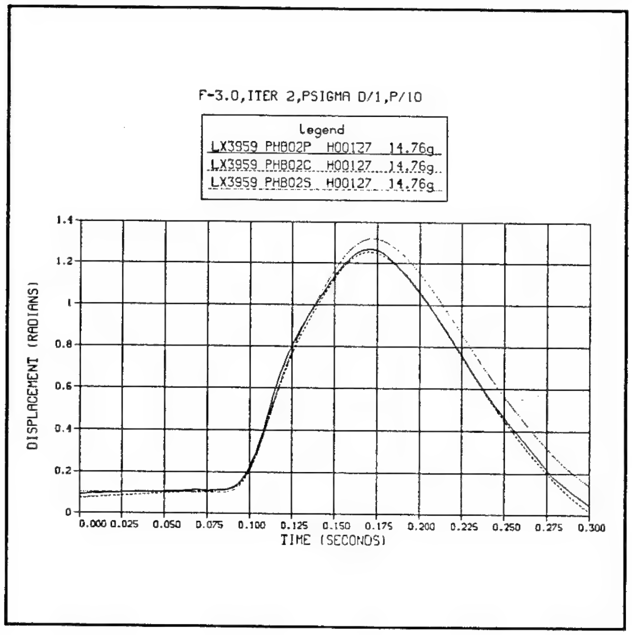


Figure C-6
Comparison of Photo-Derived (P), Marjorized (C), and Sensor-Derived (S) Rotations About Carried Head Anatomical Y Axis

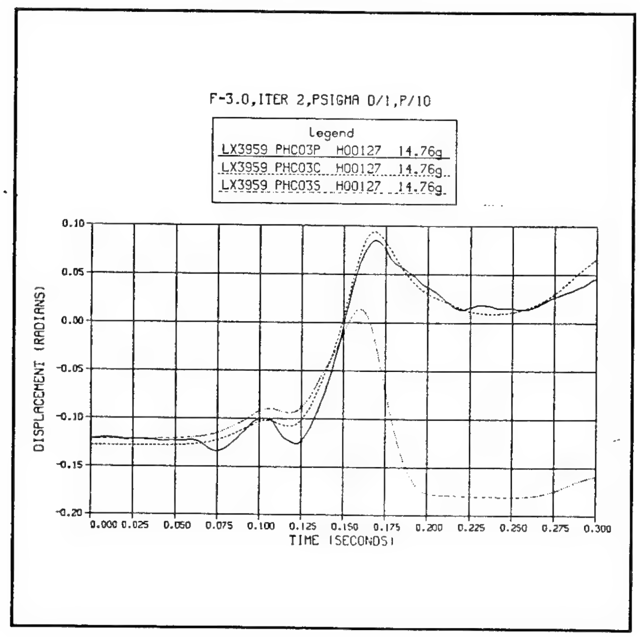


Figure C-7
Comparison of Photo-Derived (P), Marjorized (C), and Sensor-Derived (S) Rotations About Carried Head Anatomical Z Axis

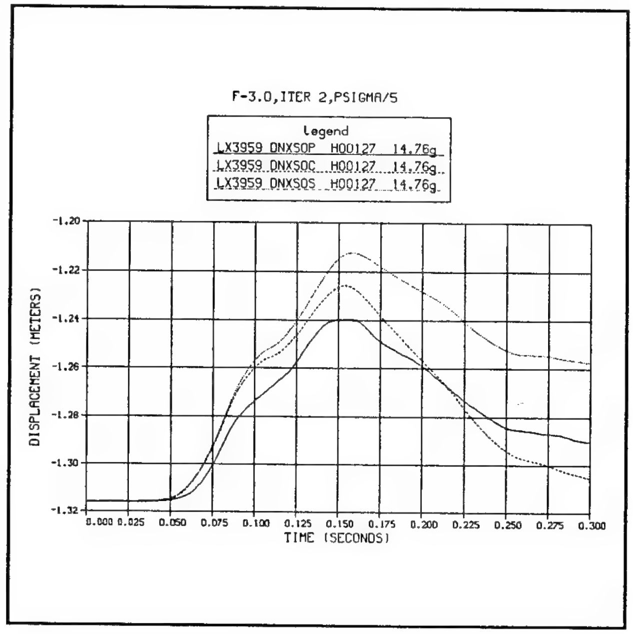


Figure C-8
Comparison of Photo-Derived (P), Marjorized (C),
and Sensor-Derived (S) T1 Anatomical X Displacements

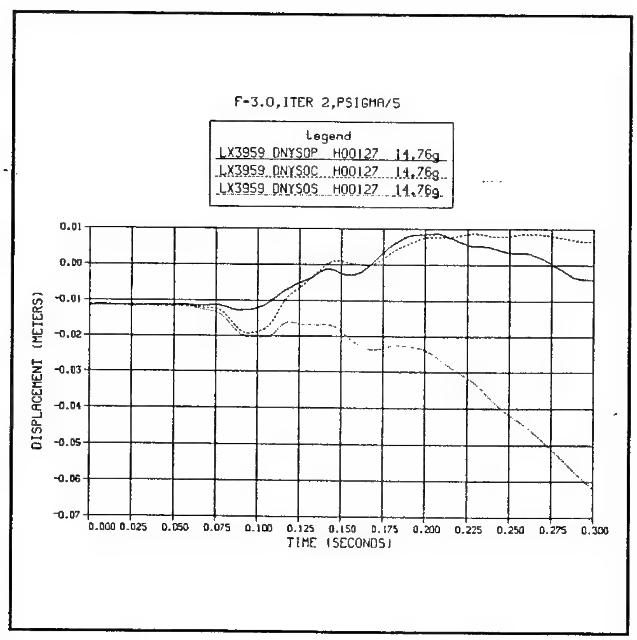


Figure C-9
Comparison of Photo-Derived (P), Marjorized (C),
and Sensor-Derived (S) T1 Anatomical Y Displacements

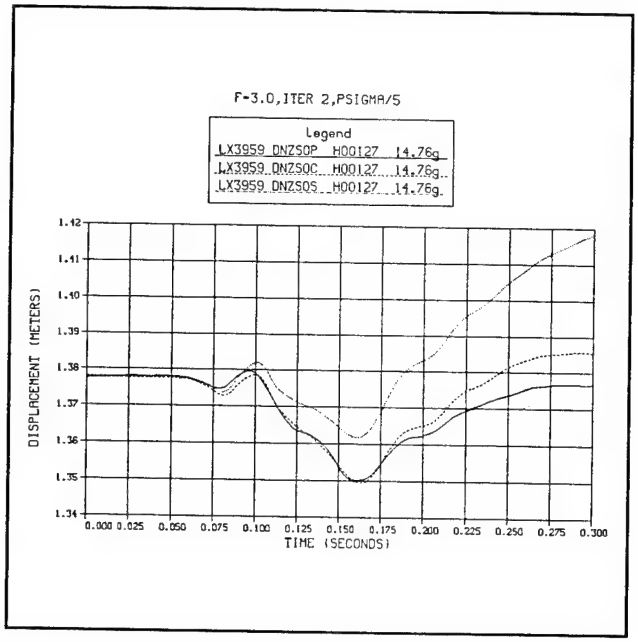


Figure C-10
Comparison of Photo-Derived (P), Marjorized (C), and Sensor-Derived (S) T1 Anatomical Z Displacements

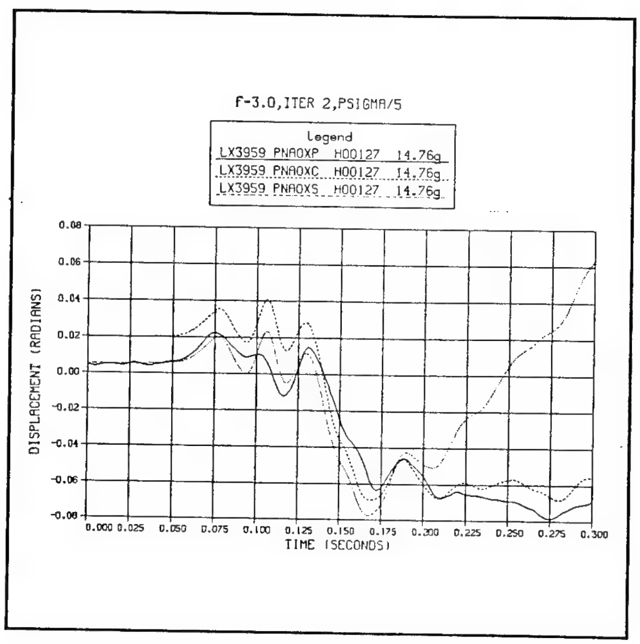


Figure C-11
Comparison of Photo-Derived (P), Marjorized (C), and Sensor-Derived (S) Rotations About T1 Anatomical X Axis

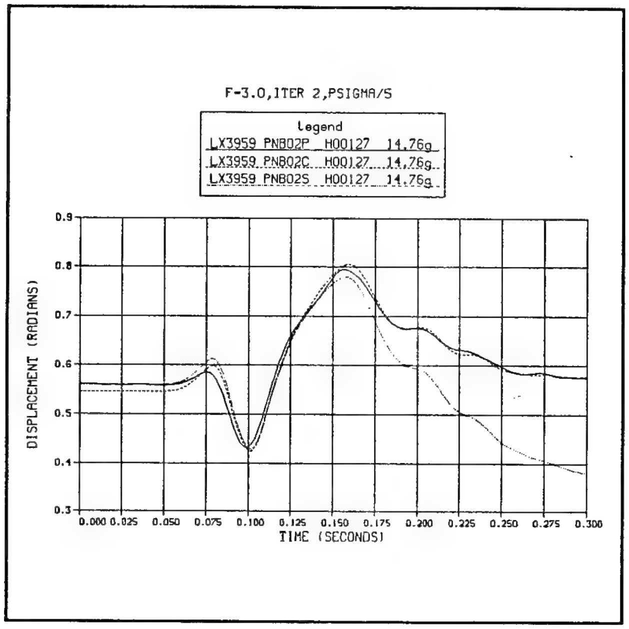


Figure C-12
Comparison of Photo-Derived (P), Marjorized (C), and Sensor-Derived (S) Rotations About Carried T1 Anatomical Y Axis

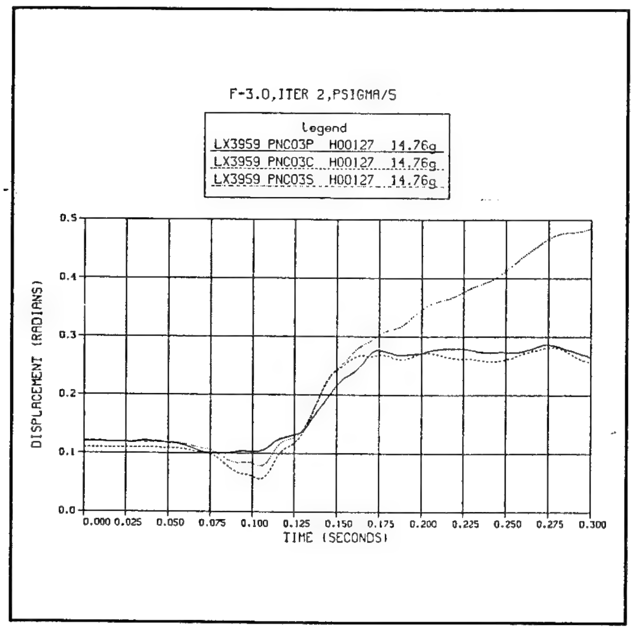


Figure C-13
Comparison of Photo-Derived (P), Marjorized (C), and Sensor-Derived (S) Rotations About Carried T1 Anatomical Z Axis

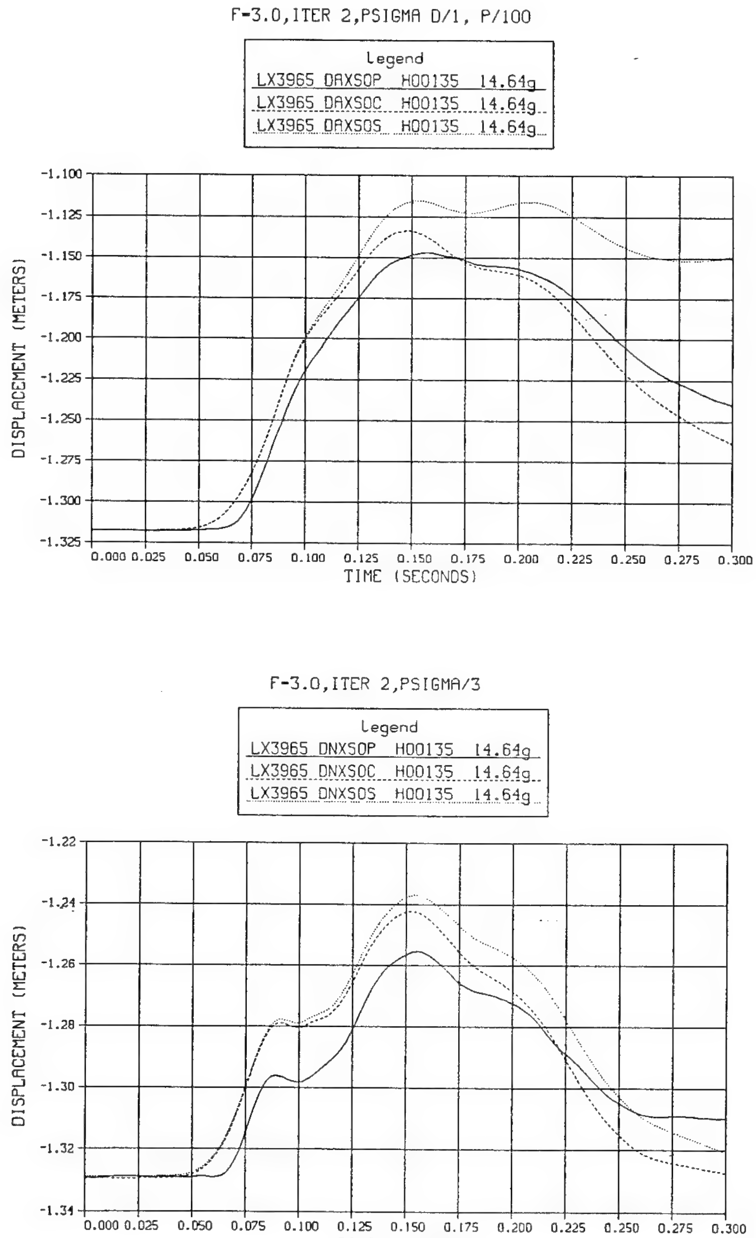
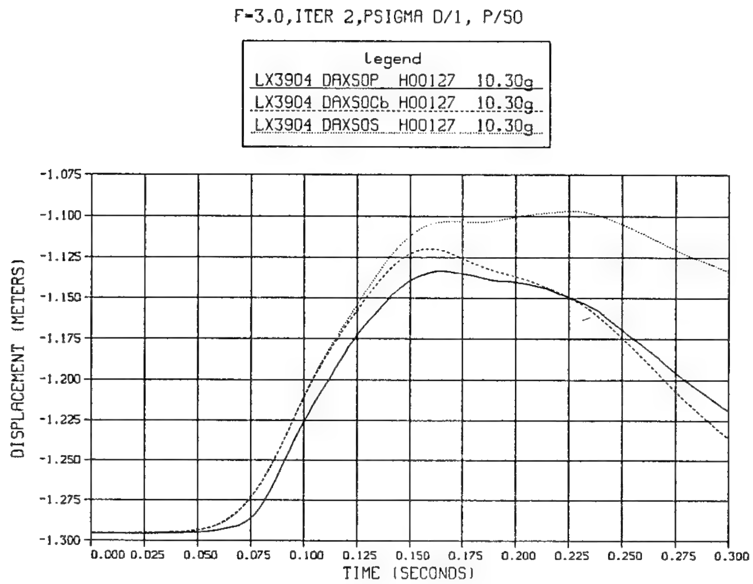


Figure C-14
Timing Discrepancies Between LX3965 Photo-Derived (P), and Sensor-Derived X Displacements for Head (top) and T1 (bottom) Anatomical Origins



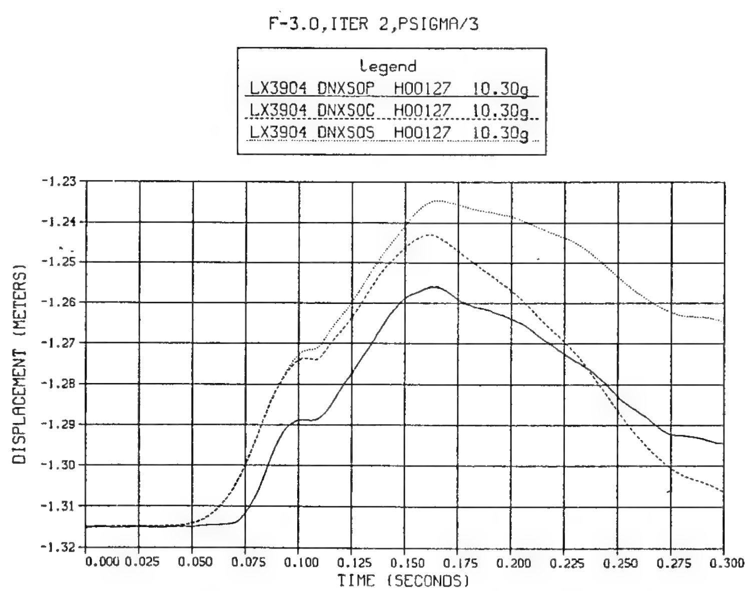
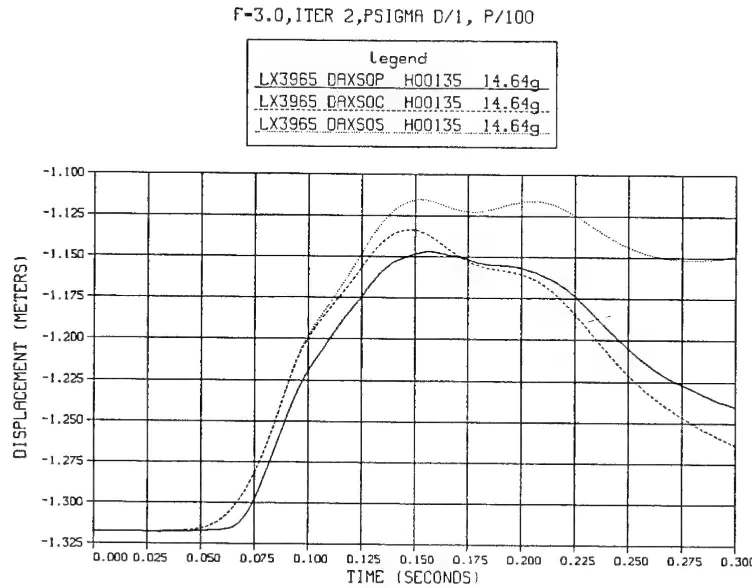


Figure C-15
Timing Discrepancies Between LX3904 Photo-Derived (P), and Sensor-Derived X Displacements for Head (top) and T1 (bottom) Anatomical Origins



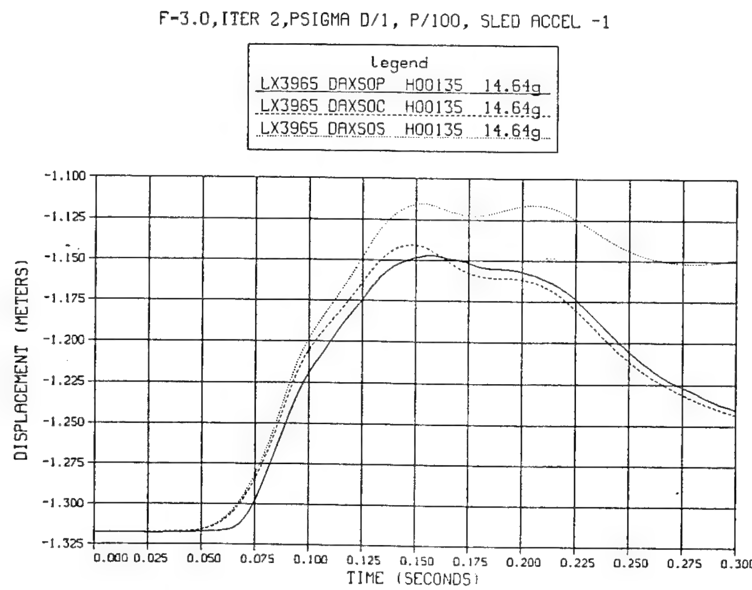


Figure C-16
Comparison of LX3965 Head X Displacements for Uncorrected Marjorized (top) and Corrected Marjorized (bottom) Reflecting 1 msec Sled Acceleration Shift

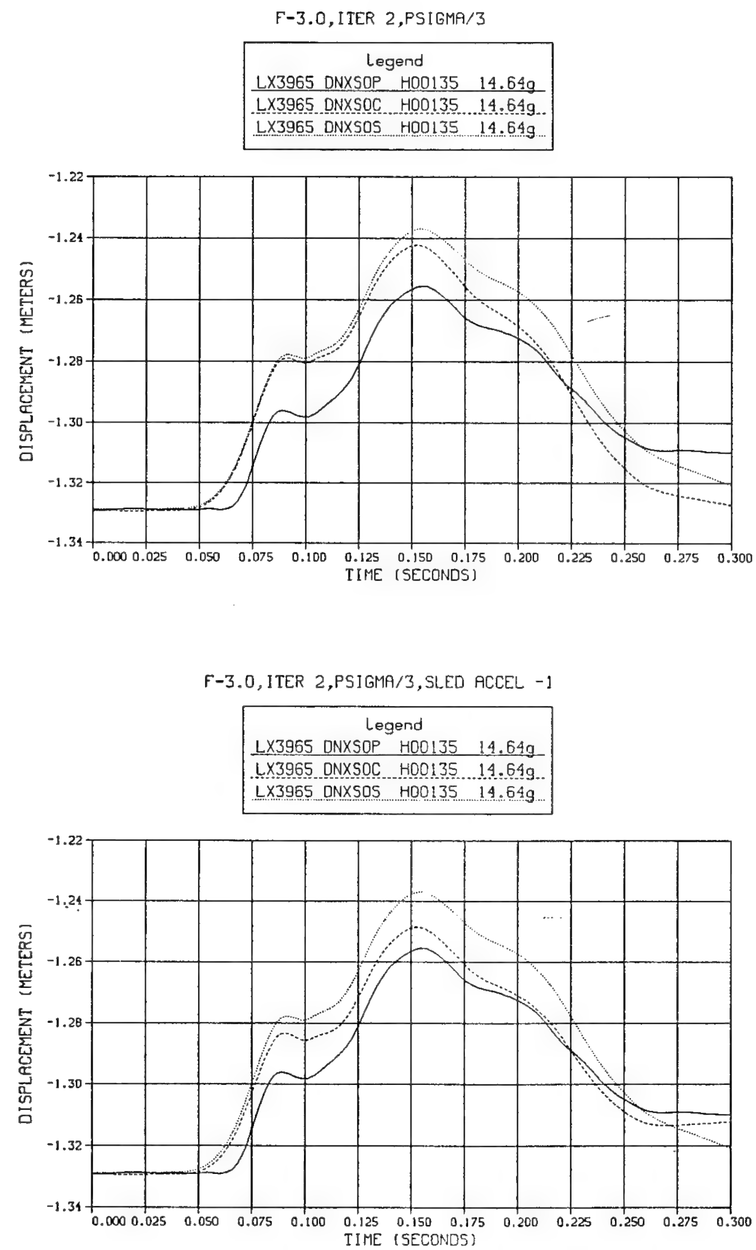
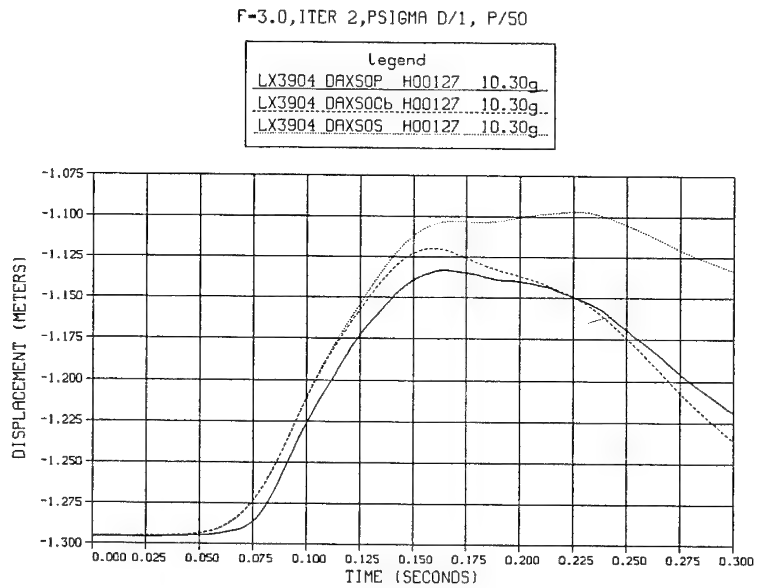


Figure C-17
Comparison of LX3965 Uncorrected Marjorized (top) and Corrected Marjorized (bottom) T1 X Displacements Reflecting 1 msec Sled Acceleration Shift



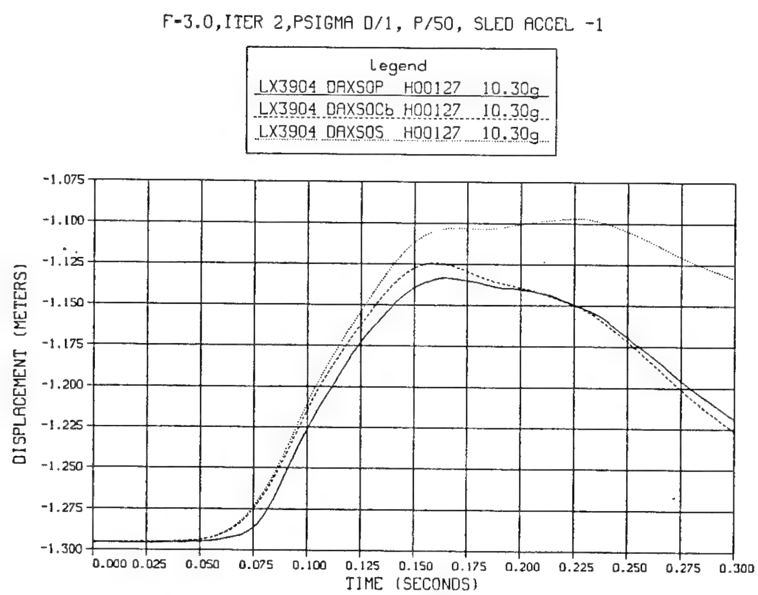


Figure C-18
Comparison of LX3904 Uncorrected Marjorized (top) and Corrected Marjorized (bottom) Head X Displacements Reflecting 1 msec Sled Acceleration Shift

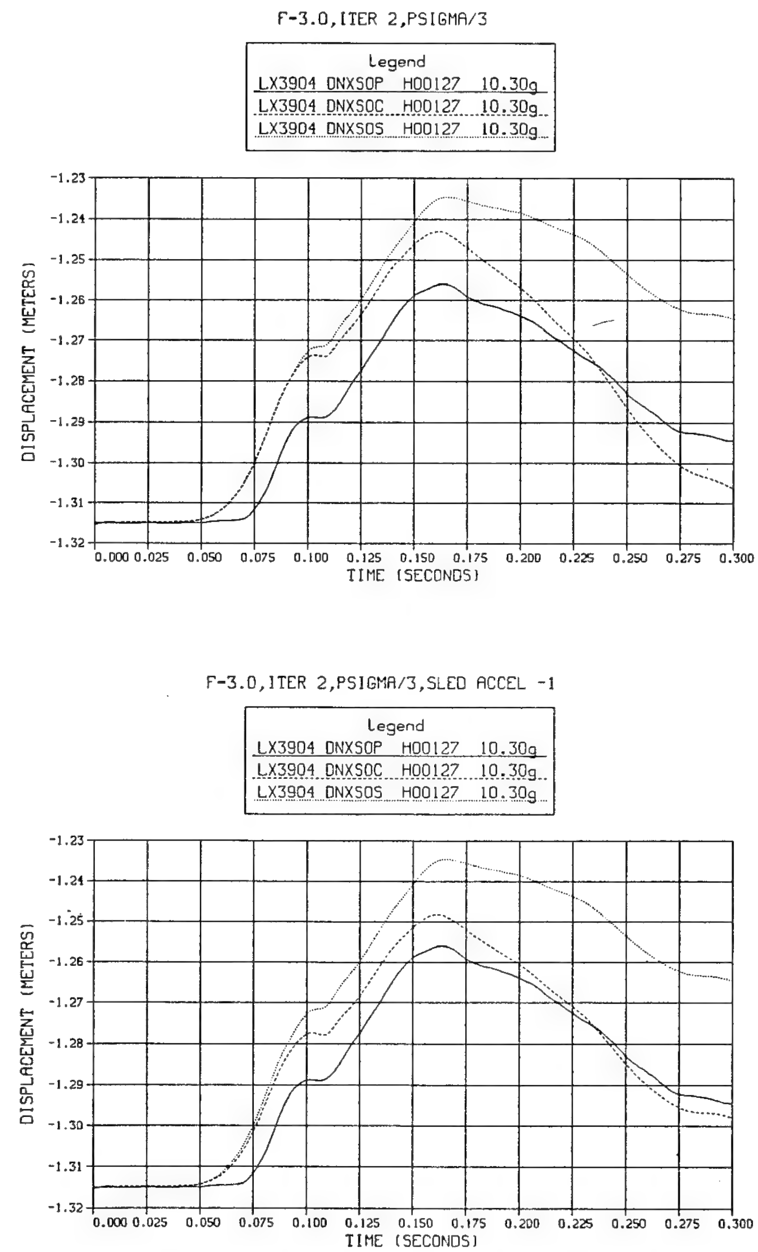


Figure C-19
Comparison of LX3904 Uncorrected Marjorized (top) and Corrected Marjorized (bottom) T1 X Displacements Reflecting 1 msec Sled Acceleration Shift

Appendix D
Tables

Table D-1. Data Files Used by the Marjorization Program

Sample User-Created Data Files

Sample User-Created Data File Name	Input to Module	Description of Data	Sample Data File	Description of Data File Name Composition
d1101	Module 1	Table D-5	Appendix B4	1101 = Anat.Mt.ID
d2201	Module 1	Table D-5	Appendix B4	2201 = Anat.Mt.ID
data1	Module 1	Table D-6	Appendix B5	–
corrzero	Module 1	Table D-11	Appendix B11	–
filein	Module 2	Table D-7	Appendix B6	–
data2	Module 2	Table D-8	Appendix B6	–
oldc3959	Module 2	Table D-11	Appendix B10	3959 = Sled Run No.
data3	Module 3	Table D-9	Appendix B7	–
marjphodat	Photo-Reformatting	Table D-10	Appendix B8	–
pltmarj	Plotting	Table D-11	–	–

Sample Program-Created Data Files

Sample Program-Created Data Files	Output by Module	Input to	Sample Data File	Description of Data
head3959	Photo-Reformatting Module	Module 1	Appendix B9	Table D-12
neck3959	Photo-Reformatting Module	Module 1	–	Table D-12
out3959	Module 1	Module 2	–	Page 9
corr3959	Module 2	Module 3	Appendix B10	Table D-11

Table D-2. Evaluation of Marjorized Variables:* Standard Factor Set Applied to Sigmas for Photo-Derived Displacements.

Head Standard Factor Set: 1D,1OP***							
Sled Runs	Head Displacement Variables (Variable Definitions in Table D-11)						MAGNITUDE OF CORRECTIONS**
	DAXSOC	DAYSOC	DAZSOC	PHAOXC	PHBO2C	PHCO3C	
LX3852	E	E	E	E	E	E	E
LX3883	E	E	E	E	E	E	E
LX3893	E	E	E	E	E	E	E
LX3904	G +	E	G	E	E	E	E
LX3924	E	E	E	E	E	E	E
LX3949	E	E	E	E	E	E	E
LX3957	G	E	E	E	E	E	E
LX3959	E	E	E –	E	E	E	G
LX3965	G	E	E	E	E	E-	E
LX3970	G-	E	**P**	E	E	E	G
LX3983	E-	E	E	E	E	E	E
LX3990	E	E	E	E	E	E	E
LX4552	E	E	E	E	E	E	E

Neck Standard Factor Set: 3D,3P***							
Sled Runs	Neck Displacement Variables (Variable Definitions in Table D-11)						Magnitude of Corrections**
	DNXSOC	DNYSOC	DNZSOC	PNAOXC	PNBO2C	PNCO3C	
LX3852	E–	E	E	E	E	E	G
LX3883	G	E	E	E	E	E	E
LX3893	N/A	N/A	N/A	N/A	N/A	N/A	N/A
LX3904	G +	E	E	E	E	E	E
LX3924	E	E–	E	E	E	E	E
LX3949	G +	E	E	E	E	E	E
LX3957	G	E	E	E	E	E	E
LX3959	G	G +	E	E	E	E	E
LX3965	G	E	E	E	E	E	E
LX3970	G +	E	E	E	E	E	E
LX3983	G	E	E	E	E	E	E–
LX3990	G +	E	E	E	E	E	E
LX4552	N/A	N/A	N/A	N/A	N/A	N/A	N/A

EVALUATION CRITERIA:

*Key for evaluating Marjorized variables (differences between Marjorized and photo-derived variables — peak to 250 msec).

Description	Key	Linear Displacements	Angular Displacements
Excellent	E	=1.25 cm	< =3 degrees
Good	G	>1.25cm, < =2.0cm	>3 degrees, < =5 degrees
Poor	P	>2.0cm	>5 degrees

**Key for evaluating corrections to accelerometer parameters (overall rating is that of the component with the largest error).

Description	Key	Accelerometer Orientation	Accelerometer Sensitivity	Initial Euler Angles
Excellent	E	< =3.5 degrees	< =3.5%	< =3 degrees
Good	G	>3.5 degrees, < =5.5 degrees	>3.5%, < =5.5%	>3 degrees, < =5 degrees
Poor	P	>5.5 degrees	>5.5%	>5 degrees

***Factor Sets: Factor sets are defined as factors dividing variances for photo-derived displacements.

The following codes were used to identify the factor sets:

D=Displacement

P=Euler angles

Table D–3. Perturbation Values Used for Accelerometer Parameters in Sample Data Files *d1101* and *d2201*[a]

Line#	Accelerometer	Component Perturbed	Nominal Value
2	1	Direction Cosine 1	0.0087178
3	1	Direction Cosine 2	0.0087178
4	1	Sensitivity	0.0060000
5	2	Direction Cosine 1	0.0061644
6	2	Direction Cosine 3	0.0061644
7	2	Sensitivity	0.0060000
8	3	Direction Cosine 1	0.0061644
9	3	Direction Cosine 3	0.0061644
10	3	Sensitivity	0.0060000
11	4	Direction Cosine 1	0.0061644
12	4	Direction Cosine 3	0.0061644
13	4	Sensitivity	0.0060000
14	5	Direction Cosine 1	0.0087178
15	5	Direction Cosine 2	0.0087178
16	5	Sensitivity	0.0060000
17	6	Direction Cosine 1	0.0087178
18	6	Direction Cosine 2	0.0087178
19	6	Sensitivity	0.0060000
20	7	Direction Cosine 1	0.0061644
21	7	Direction Cosine 3	0.0061644
22	7	Sensitivity	0.0060000
23	8	Direction Cosine 1	0.0061644
24	8	Direction Cosine 3	0.0061644
25	8	Sensitivity	0.0060000
26	9	Direction Cosine 1	0.0061644
27	9	Direction Cosine 3	0.0061644
28	9	Sensitivity	0.0060000
29		Initial Euler Angle 1	0.0435890
30		Initial Euler Angle 2	0.0435890
31		Initial Euler Angle 3	0.0435890

[a]Perturbation values shown in Appendix B4 for the data files *d1101* and *d2201* for anatomical mounts 1101 and 2201 respectively are 3-σ errors. Errors in accelerometer direction cosines and sensitivities were based on multiple calibrations of the T-Plate and were suggested by an earlier study.[5] Note that the values used for errors in the orientation of the accelerometers are different for the in-plane accelerometers and those perpendicular to the plane of the T-plate. For both mounts 1101 and 2201, accelerometers 1, 5, and 6 were perpendicular to the plane of the T-plate, while all of the other accelerometers were

inplane. 3-σ errors in initial Euler angles are estimates based on previous studies of errors in photographic data.

Entries in d2201 for anatomical mount 2201 are identical, except that there are only 6 accelerometers on the mount, so the data file only contains entries for accelerometers 1–6.

Description of entries in data file *d1101* for anatomical mount 1101:

Line 1: remarks FORMAT (A72)

Lines 2–31: perturbation values FORMAT(F15.0)

Table D–4. Input Variables in Data File *data1*[a]	
Line 1:	format(2i2)
icorr	Index to determine if corrections are to be applied to the sensor program parameters to generate perturbed values for the follow Enter 0 if corrections are not to be applied. Enter 1 if perturbations are to be applied.
iprint	Print Index Enter 0 for normal output.
Line 2:	format(a6)
test	Sled run number Enter 6 character sled number, e.g., LX3959.
Line 3:	format(a6)
	EOFEOF

[a]Input variables for Marjorization Module 1 are read from data file *data1* (see Appendix B5)

Table D-5. Input Variables in Data File *filein*[a]	
Line 1:	format(a11)
filein	The name of the file which contains the Marjorization parameters for the run. Enter 11 character data file name, e.g., data2
Line 2:	format(6f10.2)
wth(i),i=1,6	Factors to be applied to the denominators of the *a priori* error values for the head photo-derived displacements wth(1) = factor for head X displacement, nominal value 1.0 wth(2) = factor for head Y displacement, nominal value 1.0 wth(3) = factor for head Z displacement, nominal value 1.0 wth(4) = factor for head Euler angle A, nominal value 10.0 wth(5) = factor for head Euler angle B, nominal value 10.0 wth(6) = factor for head Euler angle C, nominal value 10.0
Line 3:	format(6f10.2)
wtn(i),i=1,6	Factors to be applied to the denominators of the *a priori* error values for the neck photo-derived displacements wtn(1) = factor for neck X displacement, nominal value 3.0 wtn(2) = factor for neck Y displacement, nominal value 3.0 wtn(3) = factor for neck Z displacement, nominal value 3.0 wtn(4) = factor for neck Euler angle A, nominal value 3.0 wtn(5) = factor for neck Euler angle B, nominal value 3.0 wtn(6) = factor for neck Euler angle C, nominal value 3.0

[a]Input variables for Marjorization Module 2 are read from data file *filein* (see Appendices B3 and B6).

Table D-6. Input Variables in Data File ***data2***[a]

Line 1:	format(a6,i2,i2,2f7.3)
runid	Sled run id, e.g., LX3959
iprint	Print index Set to 0 for normal output
iprior	Index to determine whether a priori terms will be used to constrain the solution for the corrections to the sensor program parameters Set to 0 for unconstrained solution.
factor	Factor to be applied to a priori variances for accelerometer direction cosines and sensitivities. Nominal value of 1 (1-10 normally acceptable).
factoreu	Factor to be applied to *a priori* variances for the initial Euler angles. Nominal value of 1 (1-10 normally acceptable).
Line 2:	format(7f7.4)
sec1(i),i=1,7	Endpoint of the ith time interval during the sled run, where the time window of interest is subdivided into 7 intervals; used for head calculations. Nominal values shown in Appendix B3.
Line 3:	format(7f7.4)
sec2(i),i=1,7	Endpoint of the ith time interval during the sled run, where the time window of interest is subdivided into 7 intervals; used for neck calculations Nominal values shown in Appendix B3.
Line 4:	format(7i3)
iskp1(i),i=1,7	Determines the number of data points used in calculations from the ith time interval. The value selected for iskp1(i) causes iskp1(i)-1 points to be skipped in the ith interval; used for head calculations. Nominal values shown in Appendix B3.
Line 5:	format(7i3)
iskp2(i),i=1,7	Determines the number of data points used in calculations from the ith time interval. The value selected for iskp2(i) causes iskp2(i)-1 points to be skipped in the ith interval; used for neck calculations. Nominal values shown in Appendix B3.

[a]Input variables for Marjorization Module 2 are read from data file *data2* (see Appendices B3 and B6)

Table D-7. Input Variables in Data File *data3*[a]	
Line 1:	format(2i2)
icorr	Index to determine if corrections are to be applied to the sensor program parameters to obtain Marjorized variables. Enter 0 if corrections are not to be applied. Enter 1 if Marjorized variables are to be obtained by applying corrections to the sensor program parameters.
iprint	Print Index Enter 0 for normal output.
Line 2:	format(a6)
test	Sled run number Enter 6 character sled number, e.g., LX3959.
Line 3:	format(a6)
	EOFEOF

[a]Input variables for Marjorization Module 3 are read from data file *data3* (see Appendix B7)

Table D-8. Input Variables in Data File *marjphodat*[a]	
Line 1:	format(i2,1x,a6)
iunit	The unit (file) containing the EZFLOW reduced photo variables. The nominal value is 7, since this is the unit on which EZFLOW expects the reduced photo variables to be stored.
runid	Sled run id, e.g., LX3959

[a]Input variables for the Marjorization photo-reformatting module, *marjphopgm.f*, are read from data file *marjphodat* (see Appendix B8).

Table D-9. Variables Included in Plot Specification Module *pltmarj*	
PLOT 1:	DAXSOP, DAXSOS, DAXSOC The component of linear displacement of the head anatomical origin along the X axis of the sled coordinate system with respect to the sled coordinate system. The sled coordinate system is aligned with the laboratory coordinate system and translates with the sled.
PLOT 2:	DAYSOP, DAYSOS, DAYSOC The component of linear displacement of the head anatomical origin along the Y axis of the sled coordinate system with respect to the sled coordinate system. The sled coordinate system is aligned with the laboratory coordinate system and translates with the sled.
PLOT 3:	DAZSOP, DAZSOS, DAZSOC The component of linear displacement of the head anatomical origin along the Z axis of the sled coordinate system with respect to the sled coordinate system. The sled coordinate system is aligned with the laboratory coordinate system and translates with the sled.
PLOT 4:	PHAOXP, PHAOXS, PHAOXC Angle of rotation of the head about the X axis of the head anatomical coordinate system as derived from mouth-mount data. The head anatomical coordinate system is initially aligned with the laboratory coordinate system.
PLOT 5:	PHBO2P, PHBO2S, PHBO2C Same as above except about the carried Y axis.
PLOT 6:	PHCO3P, PHCO3S, PHCO3C Same as above except about the carried Z axis.
PLOT 7:	DNXSOP, DNXSOS, DNXSOC The component of linear displacement of the T1 anatomical origin along the X axis of the sled coordinate system with respect to the sled coordinate system. The sled coordinate system is aligned with the laboratory coordinate system and translates with the sled.
PLOT 8:	DNYSOP, DNYSOS, DNYSOC The component of linear displacement of the T1 anatomical origin along the Y axis of the sled coordinate system with respect to the sled coordinate system. The sled coordinate system is aligned with the laboratory coordinate system and translates with the sled.
PLOT 9:	DNZSOP, DNZSOS, DNZSOC The component of linear displacement of the T1 anatomical origin along the Z axis of the sled coordinate system with respect to the sled coordinate system. The sled coordinate system is aligned with the laboratory coordinate system and translates with the sled.
PLOT 10:	PNAOXP, PNAOXS, PNAOXC Angle of rotation of the head about the X axis of the T1 anatomical coordinate system as derived from T1-mount data. The T1 anatomical coordinate system is initially aligned with the laboratory coordinate system.

Table D-9. Variables Included in Plot Specification Module *pltmarj*	
PLOT 11:	PNBO2P, PNBO2S, PNBO2C Same as above except about the carried Y axis.
PLOT 12:	PNCO3P, PNCO3S, PNCO3C Same as above except about the carried Z axis.

Table D-10. Description of Data in Reformatted Photo Data Files[a]	
Line 1: format(a4,8(10x,a6))	
head variable names[b]	"time," "daxsop," "daysop," "dazsop," "4hoo1p," "4hoo2p," "4hoo3p," "4hoo4p"
neck variable names[b]	"time," "dnxsop," "dnysop," "dnzsop," "4noo1p," "4noo2p," "4noo3p," "4noo4p"
Lines 2 . . . End of File: format(e14.8,7(1x,e15.8))	
Each line contains values for the 8 variables input on Line 1.	

[a]The Marjorization Photo Reformatting Module reformats the photo-derived linear displacement variables and quaternions in the format required by Marjorization module 2. These data are output in the following format (see Appendix B9):

[b]See Table D-9 for a definition of the variables beginning with "d", the photo linear displacement variables. The variables beginning with "4h" are head quaternions and those beginning with "4n" are neck quaternions, where quaternions are the four variables which define the angular orientation of the head or T1 anatomical coordinate system relative to the laboratory coordinate system.

Table D–11. Description of the Output Solution File from Marjorization Module 2 and Other Correction Files[a]

The solution output by Marjorization Module 2 is written to a file whose name is "corr" concatenated with the four-digit numeric portion of the sled run number, e.g., *corr3959* (Appendix B10). This file is read by Marjorization Module 1 for successive iterations and must be initialized to all zero components prior to the execution of Module 1 for the first iteration. This initialization is accomplished in the shell script *xqtmarj* (Appendix B1) by providing the file *corrzero* (Appendix B11) with all zero error components, which is copied to the file *corr3959* prior to the first iteration. The file *oldc3959* containing corrections from the previous iteration is also required as input to Marjorization Module 2, and *corr3959* must not exist when the execution of Module 2 is initiated. Script *run2* (Appendix B2) takes care of both of these requirements automatically by copying *corr3959* into *oldc3959* and deleting *corr3959* prior to executing Marjorization module 2. The file *corr3959* generated by Module 2 for the final iteration is input to Marjorization Module 3, which generates the Marjorized variables.

The error components contained in *corr3959* are presented in a more readable form in the output from Module 3 (Table D–14), in which the error components are shown as the orientation error for each accelerometer in degrees and the sensitivity error as a percentage. Initial Euler angle errors are also presented in degrees.

Line 1: Identifying information for the first anatomical mount: Run No., data type, and number of correction components. In the example shown in Appendix B10, the first mount has 9 accelerometers and therefore 30 error components.

Line 2: Correction components 1–8, where the computed correction components are for the indicated accelerometer error component for the first mount:

Correction Component	Accelerometer	Component
1	1	Direction Cosine 1
2	1	Direction Cosine 2
3	1	Sensitivity
4	2	Direction Cosine 1
5	2	Direction Cosine 3
6	2	Sensitivity
7	3	Direction Cosine 1
8	3	Direction Cosine 3

Line 3: Correction components 9–16, where the computed correction components are for the indicated accelerometer error component for the first mount:

Correction Component	Accelerometer	Component
9	3	Sensitivity
10	4	Direction Cosine 1
11	4	Direction Cosine 3
12	4	Sensitivity
13	5	Direction Cosine 1
14	5	Direction Cosine 2
15	5	Sensitivity
16	6	Direction Cosine 1

Table D-11. Description of the Output Solution File from Marjorization Module 2 and Other Correction Files[a]

Line 4:	Correction components 17–24, where the computed correction components are for the indicated accelerometer error component for the first mount:		
	Correction Component	Accelerometer	Component
	17	6	Direction Cosine 2
	18	6	Sensitivity
	19	7	Direction Cosine 1
	20	7	Direction Cosine 3
	21	7	Sensitivity
	22	8	Direction Cosine 1
	23	8	Direction Cosine 3
	24	8	Sensitivity
Line 5:	Correction components 25–30, where the computed correction components are for the indicated accelerometer error component for the first mount:		
	Correction Component	Accelerometer	Component
	25	9	Direction Cosine 1
	26	9	Direction Cosine 3
	27	9	Sensitivity
	28		Initial Euler Angle 1
	29		Initial Euler Angle 2
	30		Initial Euler Angle 3
Line 6:	Identifying information for the second anatomical mount: Run No., data type, and number of correction components. In the example shown in Appendix B10 the second mount has 6 accelerometers and therefore 21 error components.		
Line 7:	Correction components 1–8, where the computed correction components are for the accelerometer error component for the second mount described in Line 2 above.		
Line 8:	Correction components 9–16, where the computed correction components are for the accelerometer error component for the second mount described in Line 3 above.		
Line 9:	Correction components 17–21, where the computed correction components are for the indicated accelerometer error component for the second mount:		
	Correction Component	Accelerometer	Component
	17	6	Direction Cosine 2
	18	6	Sensitivity
	19		Initial Euler Angle 1
	20		Initial Euler Angle 2
	21		Initial Euler Angle 3

[a]The following variable descriptions apply to the solution output by Marjorization module 2 as shown in the sample output file

corr3959 in Appendix B10. These descriptions also apply to files *corrzero* and *oldc3959*.

Table D-12. Evaluation of Marjorized Variables[a]								
Customized Factor Sets Applied to Sigmas for Photo-Derived Displacements								
		Head displacement variables (definitions in Table D-11)						
Sled Runs	Factor Set[b]	DAXSOC	DAYSOC	DAZSOC	PHAOXC	PHBO2C	PHCO3C	Magnitude of Corrections[c]
LX3904	3D,50P	G+	E	E	E	E	E	G+
LX3970	3D&P,10Z	E	E	E	E	E	E	G
		Neck displacement variables (definitions in Table D-11)						
Sled Runs	Factor Set[b]	DNXSOC	DNYSOC	DNZSOC	PNAOXC	PNBO2C	PNCO3C	Magnitude of Corrections[c]
LX3959	10D,10P	G+	E	E	E	E	E	E

The following codes were used to identify the factor sets:

D = Displacement

P = Euler angles

Z = Z displacement

Evaluation criteria:

[a]Key for evaluating marjorized variables (Differences between marjorized & photo-derived variables — peak to 250 msec)			
Description	Key	Linear Displacements	Angular Displacements
Excellent	E	< = 1.25 cm	< = 3 degrees
Good	G	> 1.25 cm, < = 2.0 cm	> 3 degrees, < = 5 degrees
Poor	P	> 2.0 cm	> 5 degrees

[b]Factor sets:

Factor sets are defined as factors dividing variances for photo-derived displacements.

[c]Key for evaluating corrections to accelerometer parameters (Overall rating is that of the component with the largest error)				
Description	Key	Accelerometer Orientation	Accelerometer Sensitivity	Initial Euler Angles
Excellent	E	< = 3.5 degrees	< = 3.5%	< = 3 degrees
Good	G	> 3.5 degrees, < = 5.5 degrees	> 3.5%, < = 5.5%	> 3 degrees, < = 5 degrees
Poor	P	> 5.5 degrees	> 5.5%	> 5 degrees

Table D-13. Evaluation of Marjorized Variables[a]								
Sled Runs	Factor Set[b]	Head displacement variables (definitions in Table D-11)						Magnitude of Corrections[c]
		DAXSOC	DAYSOC	DAZSOC	PHAOXC	PHBO2C	PHCO3C	
LX3904	1D,2OP	E−	E	E	E	E	E	E−
LX3965	1D,100P	E	E	E	E	E	G+	E
Sled Runs	Factor Set[b]	Neck displacement variables (definitions in Table D-11)						Magnitude of Corrections[c]
		DNXSOC	DNYSOC	DNZSOC	PNAOXC	PNBO2C	PNCO3C	
LX3904	3D,3P	E	E	E	E	E	E	E
LX3965	3D,3P	E	E	E	E	E	E	E

Customized factor sets applied to sigmas for photo-derived displacements sled acceleration; trace shifted to the left by 1 msec

The following codes were used to identify the factor sets:

D = Displacement

P = Euler angles

H = Head

N = Neck

Z = Z displacement

EVALUATION CRITERIA:

[a]Key for evaluating Marjorized variables

(Differences between Marjorized & photo-derived variables — peak to 250 msec)

Description	Key	Linear Displacements	Angular Displacements
Excellent	E	< = 1.25 cm	< = 3 degrees
Good	G	> 1.25 cm, < = 2.0 cm	> 3 degrees, < = 5 degrees
Poor	P	> 2.0 cm	> 5 degrees

[b]factor sets:

Factor sets are defined as factors dividing variances for photo-derived displacements.

Note that the old weighting scheme using up to 60 data points was used for these runs, since this work was done before the new weighting scheme which uses up to 150 data points was implemented.

[c]Key for evaluating corrections to accelerometer parameters (Overall rating is that of the component with the largest error)				
Description	Key	Accelerometer Orientation	Accelerometer Sensitivity	Initial Euler Angles
Excellent	E	< =3.5 degrees	< =3.5%	< =3 degrees
Good	G	>3.5 degrees, < =5.5 degrees	>3.5%, < =5.5%	>3 degrees, < =5 degrees
Poor	P	>5.5 degrees	>5.5%	>5 degrees

Table D-14. Computed Corrections on Second Iteration — LX3959[a]									
Head corrections: baseline factors applied to denominators of head photo-derived displacement variances (linear displacement factor: 1, angular displacement factor: 10)									
Accelerometer	1	2	3	4	5	6	7	8	9
Orientation (degrees)	1.81	1.11	0.46	1.94	3.36	2.24	0.55	0.79	0.90
Sensitivity (%)	−3.28	1.37	0.04	0.81	−3.50	−3.25	0.54	0.40	0.16
Euler angle	1	2	3						
Initial orientation (degrees):	0.63	−0.98	−0.48						
Neck corrections: baseline factors applied to denominators of neck photo-derived displacement variances (linear displacement factor: 5, angular displacement factor: 5)									
Accelerometer	1	2	3	4	5	6			
Orientation (degrees)	1.60	4.75	0.90	1.70	1.03	1.61			
Sensitivity (%)	2.69	−2.10	0.26	2.25	−0.02	−2.34			
Euler angle	1	2	3						
Initial orientation (degrees):	0.38	−1.06	−0.67						

[a]Note that the old weighting scheme using up to 60 data points was used for these runs, since this work was done before the new weighting scheme which uses up to 150 data points was implemented.

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13. ABSTRACT *(Maximum 200 words)*

Use of kinematic data in mathematical modeling often requires a consistent set of kinematic variables from the acceleration to the displacement level. A method termed Marjorization was previously developed to combine photographic- and sensor-derived variables in an optimal way to produce a consistent set of kinematic variables, which are called Marjorized variables. The computer program that implemented this method was developed in the 1980s on the UNIVAC computer. To allow Marjorized variables to be generated on the HP9000/835, a revised version of this program has now been implemented on this platform at the Naval Biodynamics Laboratory. This new implementation of the Marjorization program incorporates changes and improvements that have been made to the EZFLOW data analysis programs and other desired program modifications. This report describes the modified version of the Marjorization program now operational on the HP9000/835 and provides detailed instructions on using the program.

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Marjorization; computer software; kinematic variables; optimum combination.

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